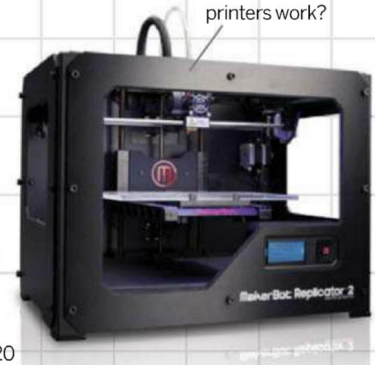
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How do 3D printers work?



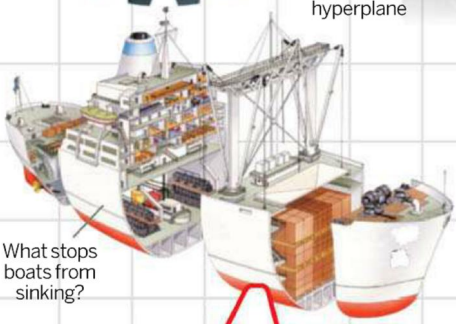
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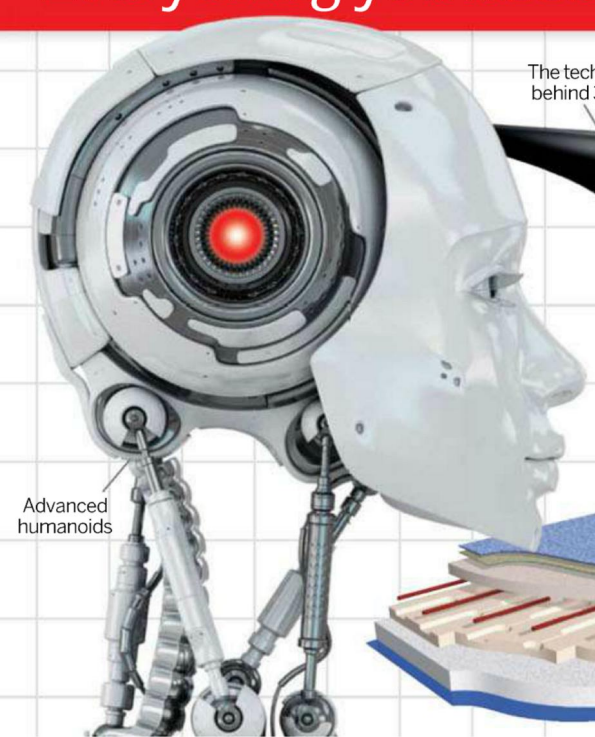


What stops boats from sinking?

HOW IT WORKS BOOK OF Amazing TECHNOLOGY

Volume 2

Everything you need to know about the world's best tech



Advanced humanoids

The technology behind 3D TVs





The world's most intelligent robots

What makes the iPad's screen so special?



How underfloor heating works

INSIDE: 1,100 AMAZING FACTS

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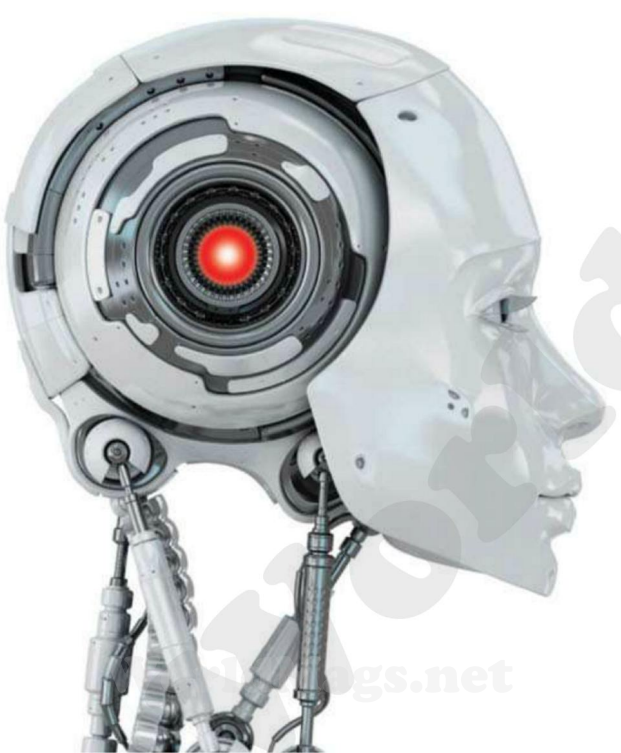
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Welcome to

HOW IT WORKS BOOK OF Amazing TECHNOLOGY

There's no doubt that technology in all its forms has become an integral part of our lives. Yet despite its importance, very few of us understand exactly how it all works. However, Volume 2 of the How It Works Book Of Amazing Technology will educate and inform readers about some of the world's most spectacular buildings, innovative gadgets and useful domestic appliances. With our in-depth guides, fascinating facts and detailed cutaway images, you'll learn about everything from supersmart structural engineering to what's inside an iPad. If you've ever wondered how to broadcast live sports events, what a 3D printer does, what's in a nuclear reactor or even how the internet works, you'll find all the answers you're looking for right here.



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IMAGINE PUBLISHING

IMAGINEER OF THE YEAR
WILLIAM SHUM

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HOW IT WORKS

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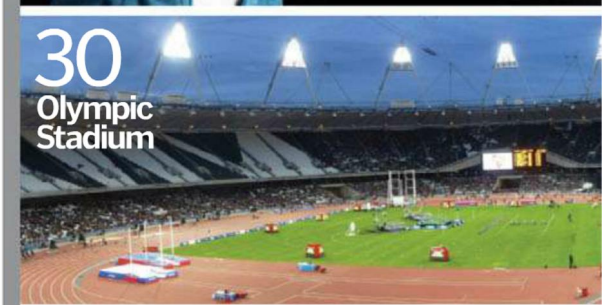
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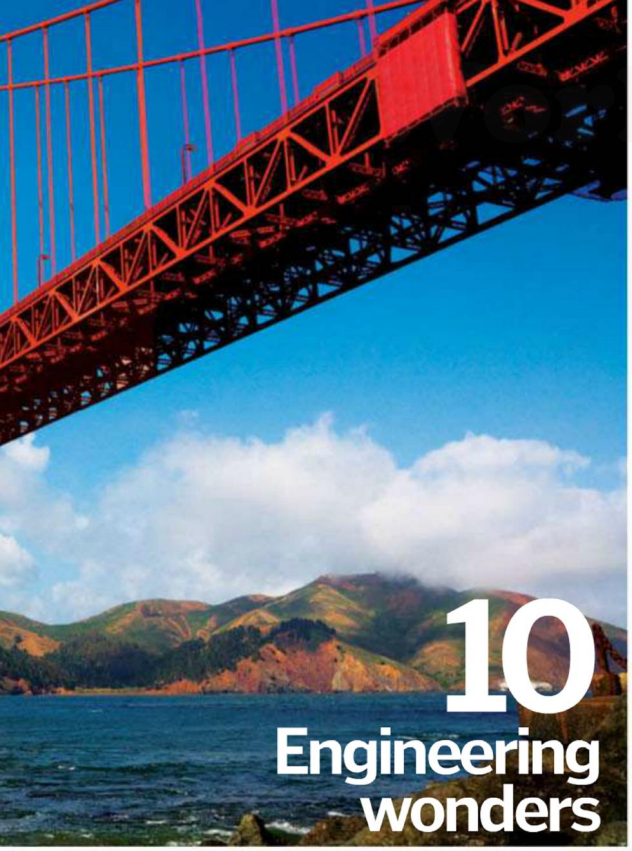
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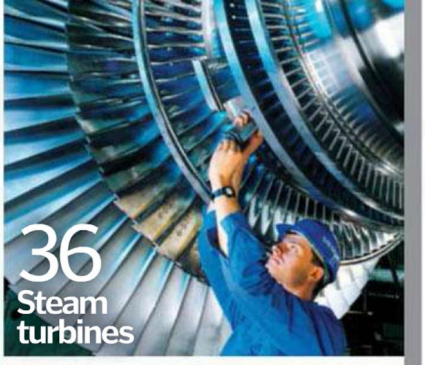




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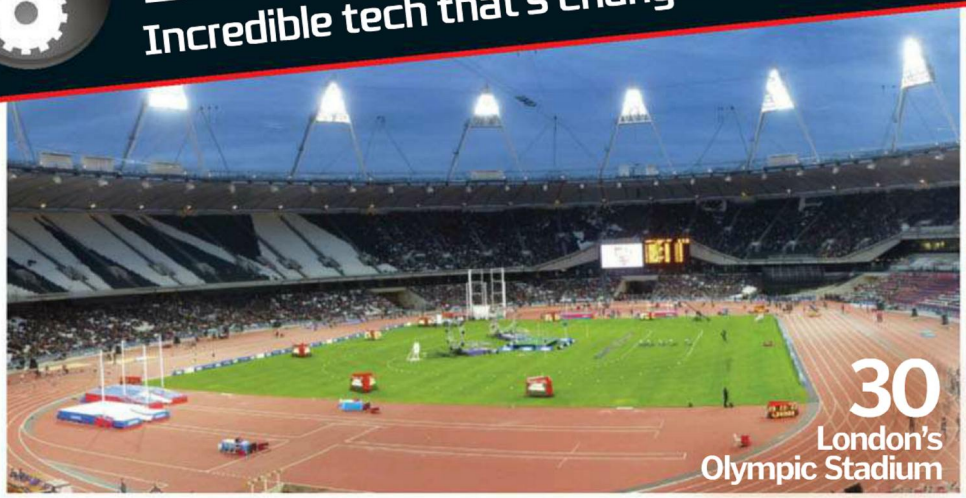


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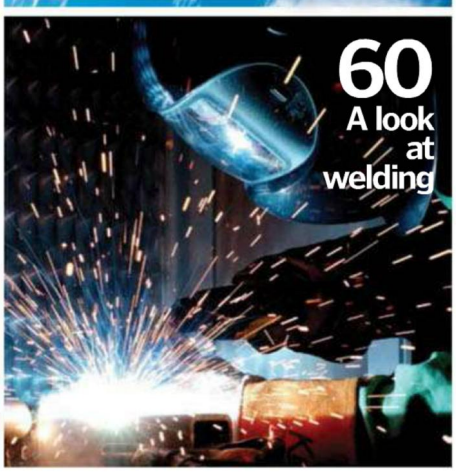
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"Engineers today are the wizards, alchemists and even gods of yesteryear"





7 ENGINEERING WONDERS OF THE WORLD

Humankind's engineering ingenuity is pushing out a new wave of mechanical, electrical and structural wonders, superseding their predecessors in every way, delivering mind-bending levels of power, speed and strength. We take a look at some of the best examples...

How far can we manipulate matter? Bend the conventional rules of physics? To what extent can we push the engineering envelope to create mechanical wonders that not only broaden humanity's horizons but also reaffirm the ability of science and technology to improve people's lives? The answer, it seems, is further than anyone ever thought possible.

Engineers today are the wizards, alchemists and even gods of yesteryear, achieving miracles that once would have been deemed impossible. Thanks to their judicious study of mathematics, geometry, algebra and material sciences, today's top engineers can defy gravity, travel across the Earth in mere hours and create computational systems to explore reality at a quantum scale. And all this is just for starters... once they get going there's no way of knowing what could come next.

Like the heroic fables of old, these achievements should be celebrated and, as such, **we have** put together a list of seven of the modern world's most spectacular engineering accomplishments for your viewing pleasure. From hypercars and seven-star hotels, through to monstrous 45,000-ton earth excavators and on to hypersonic jets that are capable of travelling at around 21,000 kilometres (13,000 miles) per hour, what follows are some of the mechanical marvels currently pushing the boundaries.

5 TOP FACTS THE ANCIENT WONDERS

Original
1 The original list of the world's seven wonders stems from the 1st century BCE, where Hellenic tourists would visit numerous sites around the Mediterranean.

The survivor
2 Of the seven wonders of the ancient world, only one remains on today's list: the Great Pyramid of Giza. The others are now either ruins or completely destroyed.

Helios
3 Of the ancient wonders, one of the most impressive was the Colossus of Rhodes, a 33-metre (107-foot)-tall statue of the Greek Titan Helios. It was destroyed in an earthquake in 226 BCE.

Lighthouse
4 Another of the most notable ancient wonders was the Lighthouse of Alexandria, which at the time was the largest structure on Earth. An Egyptian proposal to rebuild it was tabled in 2008.

Myth
5 One of the ancient wonders is considered by many to be a myth. The Hanging Gardens of Babylon were said to have been built in the 6th century BCE, however no first-hand evidence exists.

DID YOU KNOW? *The Agera R can accelerate from 0-200mph in a mere 17.68 seconds*



The advanced hypercar

Like a brutal blow to the face by Thor's warhammer, Koenigsegg's Agera R demolishes traditional ideas of speed and power in a fury of burnt hydrocarbons

Can you race a lightning bolt? Well, considering that would mean travelling at close to 225,000 kilometres (140,000 miles) per hour, probably not. Nevertheless, Swedish hypercar manufacture Koenigsegg is giving it its best shot with its latest model – the Agera R – which is capable of obliterating the 440-kilometre (273-mile)-per-hour mark without even breaking a sweat.

> *"The Agera R is capable of obliterating 440 kilometres (273 miles) per hour without even breaking a sweat"*

We're talking about a vehicle with a colossal 850 kilowatts (1,140 horsepower), earth-moving torque of over 1,200 Newton metres (885 foot pounds) at 4,100rpm, an intense 1.4 bar turbo boost pressure, a lateral g-force of 1.6 g, a pure aluminium five-litre (1.3-gallon) V8 engine and a carbon-fibre intake manifold with optimised intake tract. Not only this, but this hypercar delivers all of these things at a stupidly low (dry) weight of just 1,330 kilograms (2,932 pounds) and, as such, can accelerate from 0-60 miles per hour in an eye-watering 2.9 seconds.

Talking of statistics, the Agera R isn't a mere flash-in-the-pan in terms of speed, topping out after an initial burst of energy. Shift up through its seven-speed, dual-clutch transmission and then employ ventilated ceramic disc brakes with six-piston callipers, and you'll find yourself moving from 0-200 miles per hour and then back to 0 in just 21.2 seconds. How is this possible? To name but one of many reasons, it's down to the fastest and most efficient traction control system in the motoring sphere.

Highly qualified engineers have delivered the lightest, most compact hypercar engine in the world, complete with a clutch, flywheel, dry sump and Inconel manifold system with turbos, all in a package that weighs less than 200 kilograms (441 pounds). It also boasts a revolutionary new response/back-pressure reduction system to grant the Agera R instantaneous turbo response. Further, these engineers have designed waterless, air-to-air intercoolers for the vehicle, both reducing weight and improving acceleration speed significantly.


A semi-stressed engine and gearbox with support struts deliver optimal rigidity

The statistics...

Agera R

Length: 4,293mm (169in)
Width: 1,996mm (78.6in)
Height: 1,120mm (44.1 in)
Dry weight: 1,330kg (2,932lb)
Engine: 5l (1.3ga) V8
Power: 850kW (1,140hp)
Max speed: 440km/h (273mph)
Max torque: 1,200Nm (885ft lb) at 4,100rpm
0-60mph: 2.9 seconds
Lateral g-force: 1.6 g
Chassis: Carbon fibre with aluminium honeycomb

Extreme engineering

We break down the exterior of a car that's designed for a life in the fast lane



Windshield
A huge, swept panoramic windshield delivers optimal visibility in-car.

Wing
A dynamically movable rear wing ultimately allows downforce to be controlled by the driver.

Splitter
A cut-out splitter ensures that airflow reaches the rear diffuser during braking and promotes constant downforce.

Vents
Vents over the Agera R's wheel arches reduce drag and increase downforce.

Intakes
Large, tapered side intakes ensure the R's pressure point is behind its mass centre, adding directional stability at high speeds.

4x © Koenigsegg

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"The entire building – including its artificial island base – only took five years to construct"

2

The seven-star super-structure

The Burj Al Arab hotel boasts a $650m, sail-inspired design and sits on its own man-made island

The statistics...



Burj Al Arab

Cost: £400m ($650m)
Rooms: 205
Floors: 70
Height: 320m (1,053ft)
Total floor area: 111,500m² (1,200,000ft²)

Atrium
The Al Arab's atrium is one of the largest in the world, standing at a huge 180m (590ft) high.

Foundations
The Al Arab is built on a surface layer of large rocks, which is encircled with a concrete honeycomb-patterned foundation.

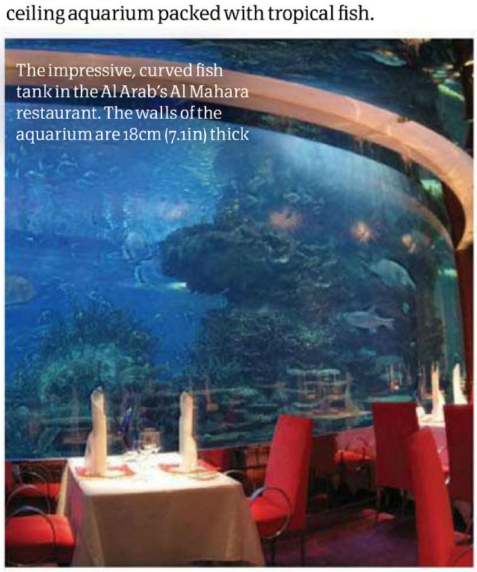
Piles
The hotel sits on a wholly man-made island, created by driving 230 40m (131ft) concrete piles deep into the ocean bed.

A revolutionary new architectural design, the Burj Al Arab hotel in Dubai is currently one of the planet's most impressive buildings. Its engineers designed it to resemble the sail of a dhow sailing vessel, with two reinforced concrete wings acting as the building's V-shaped mast, and the sail consisting of the atrium's mainly glass rear curve.

A stunning building such as this is only made possible thanks to recent advances in concrete reinforcement, as well as the ability to manufacture lightweight steel – of which the Al Arab sports 9,000 tons – and strengthened, curved glass. Due to its construction on a totally artificial island, which was created by driving huge concrete piles into the seabed, an advanced foundation structure also needed to be realised, with the hotel resting on a honeycomb base; this grants staggering strength and also malleability for resisting constant shifts in the Earth's surface.

All of this is pretty impressive. It becomes astounding, however, when you factor in that the entire building – including its artificial island base – only took five years to construct. Speaking on its opening, an architectural critic said: "This extraordinary investment in state-of-the-art construction technology stretches the limits of the ambitious urban imagination."

Speaking of astounding, the hotel also comes with its very own gravity-defying helipad at the tip of the 'sail', so guests can come and go without ever touching the ground, as well as a restaurant with a floor-to-ceiling aquarium packed with tropical fish.



The impressive, curved fish tank in the Al Arab's Al Mahara restaurant. The walls of the aquarium are 18cm (7.1in) thick

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1. DEADLY

M203
A launcher designed to attach to the M16 and M4 Carbine rifles, the M203 fires single-round 40mm (1.6in) ordnance to a range of 150m (490ft).



2. DEADLIER

M-32 MGL
A lightweight, multiple-round grenade launcher, the M-32 MGL can fire a maximum six 40mm (1.6in) grenades per cartridge up to 375m (1,230ft).



3. DEADLIEST

XM25 CDTE
A handheld grenade launcher that can fire a variety of 25mm (0.98in) programmable smart ordnance to an effective range of 700m (2,300ft).

DID YOU KNOW? *A single XM25 CDTE grenade launcher would set you back $25,000 (£15,700)*



3 The ultimate weapon

Weapons don't come much more devastating than the XM25 CDTE grenade launcher, aka the Punisher



US special forces teams have recently deployed the Punisher in Afghanistan

Think a Counter Defilade Target Engagement system (CDTE) sounds boring? Does it conjure up an image of a tool for deflating tyres? Well, think again. Because that system is actually the most technologically advanced weapon currently on the planet.

And what a weapon it is. The XM25 CDTE is a culmination of decades of engineering forged into an incredibly powerful tool that can change any warzone it is fielded in. It's a handheld semi-automatic grenade launcher that can propel a wide variety of munitions up to 700 metres (2,300 feet) and cause massive damage against any imaginable targets. Not excited yet? Well, this handheld grenade launcher can not only directly fire explosive rounds, but also program each wirelessly, and on the fly, to explode at a set distance or at a set time, to ensure it never misses its target. Sounds a little more impressive now, doesn't it?

Indeed, this weapon truly is a 'system' rather than a mere gun, with each unit equipped with an in-built ballistic computer, digital compass, fuze setter, environmental sensor array, laser rangefinder, 4x thermal sight with digital zoom and XM104 target acquisition and fire control chipset. All this is packed into a rifle that weighs less than 6.4 kilograms (14.1 pounds) – that's the equivalent of just three bags of sugar. Combine these components and you are ready to stir up a whole gunboat-load of trouble for enemy forces.

Are you facing troops dug in deep, sheltering behind reinforced cover or hiding within the ground? That's no challenge for the XM25 – simply laser the position with the Punisher's rangefinder, aim and watch a programmed round loop with pinpoint accuracy over the obstacle and then explode at the optimum moment in a devastating air burst.

Or perhaps you have a squad of enemy forces rumbling your way in an armoured personnel carrier? No problem, because if you select the XM25's armour-piercing ordnance, you have a weapon that can penetrate the APC's hull with ease.

The versatility of the XM25 CDTE is on a whole different level to any other weapon ever engineered and this is reflected in the US Army's decision to introduce 12,500 Punishers to its troops throughout 2012.

The statistics...



XM25 CDTE

Weight: 6.4kg (14.1lb)
Length: 749mm (29.5in)
Cartridge: 25mm (0.98in) explosive ordnance
Muzzle velocity: 210m/s (690ft/s)
Range: Up to 700m (2,297ft)
Feed: 4-round box magazine
Operation: Gas operated, semi-automatic
Electronics Ballistic computer, digital compass, environmental sensor, laser rangefinder

How the Punisher works

We examine the handheld weapon so explosive it could level your house with a single round



Magazine
The rifle comes with a four-round box magazine as standard, which can carry the weapon's wide range of ordnance types without any modification.

Laser
As well as the Punisher's 4x thermal sight and 2x optical sight, it is also equipped with a next-gen laser rangefinder. This allows distance to target to be acquired rapidly in the field.

Control
The XM25's XM104 control system is state of the art, allowing its user to program the rifle to set fired munitions to explode at a certain distance or after a set period of time. Desired round distances and times are automatically transmitted to each grenade.

Barrel
The rifle features a semi-automatic gas operation that propels rounds down the CDTE's rifled barrel at 210m (690ft) per second. The barrel's rifling is incredibly fine, as after a distance-set round has been fired, it tracks its own progress by measuring its total spiral rotations.



Ammo
The XM25 CDTE can fire a variety of programmable ordnance including: thermobaric, flechette, airburst, armour-piercing and door-breaching grenades.

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"If you need to move a mountain then what you really need is the Krupp Bagger 288"

4 The mechanical monster

The world's biggest land vehicle, the Krupp Bagger 288 is larger than an Ancient Greek Titan and heavier than Titanic



The Bagger 288 can excavate 240,000 tons of coal or earth each day; that is the equivalent size of a football field dug to a depth of 30m (98ft)

© JaySet

If you need to move a mountain then what you really need is the Krupp Bagger 288, the world's largest and most awe-inspiring bucket excavator. And when we say large, we really mean titanic in scale, a behemoth and mechanical monster that dwarfs men, other vehicles and structures alike, as if they were all merely bugs.

This giant earth digger was designed by German company Krupp (now ThyssenKrupp) to literally hollow out mountains in Germany in search of coal, which it then excavates with savage efficiency, piling bucket after bucket of soil and rock into its auxiliary storage bins. From its huge containers, the material – hopefully containing coal or other valuable minerals – is automatically carried through its huge body and out on to massive conveyer belts which lead to a processing facility. To put its capabilities in context, the Bagger 288 can fill 2,400 coal wagons in a single day!

The statistics...



© ThyssenKrupp

Krupp Bagger 288

- **Height:** 94m (311ft)
- **Length:** 214m (705ft)
- **Chassis width:** 46m (151ft)
- **Weight:** 45,500 tons
- **Max speed:** 0.6km/h (0.37mph)
- **Turning radius:** 100m (328ft)
- **Power consumption:** 16.6MW

Learn your way around the Krupp Bagger 288

We explore the machine so powerful it can sculpt the surface of the Earth at a whim

Power

Due to its vast size the Bagger 288 requires 16.6MW of externally supplied electricity to power its excavator, tracks, chassis and transmission.

Tracks

The 288's chassis sits on three rows of four caterpillar track assemblies, each 3.8m (12ft) wide. The large surface area of the tracks grants the Bagger a ground pressure of just 1.8kg/cm² (24.8psi).

Crew

It takes five people to operate the 288 and over 70 to move it. If the Bagger crosses any roads, once it is clear they must be totally rebuilt, as its insane weight crushes the concrete.



DID YOU KNOW? US defence contractor Lockheed Martin became the first to purchase a D-Wave One in May 2011

The reason why the 288 doesn't deliver the material itself is due to its immense weight, tortoise-slow movement speed and colossal turning circle. That is not to say that the 288 is incapable of relocating itself – indeed, it frequently moves around stripmines in Germany – however movement remains a very cumbersome affair.

For example, in February 2001, the 288 had totally exposed all of the coal located in the Tagebau Hambach stripmine and therefore was no longer needed in the area. As such, it was deemed that the Bagger should be relocated 23 kilometres (14 miles) down the road to the Tagebau Garzweiler mine. While this short distance would have been covered by a standard road vehicle in a matter of minutes, the 288 took three weeks to complete the journey and it cost the operator over £6m ($9.9m). Further, over 70 engineers were needed at all times to ensure its safe passage, which necessitated it crossing the large Autobahn 61 motorway, the River Erft, a railway line and numerous roads.

Interestingly – and maybe the greatest engineering feat of the Bagger's construction – due to its designers specifying the 288's tracks with such a large surface area, the vehicle's ground pressure is – relative to its size – incredibly small, clocking in at under two kilograms per square centimetre (25 pounds per square inch). This small ground pressure means that the Bagger can traverse a wide array of terrains, including grass, gravel, earth and tarmac – nevertheless roads still need to be resurfaced in its wake.





The computing breakthrough

The D-Wave One quantum computer can solve problems a million times faster than today's supercomputers

The D-Wave One quantum computer – technically known as a 'quantum optimiser' – works differently to classical computers in many ways. However, the most important is its abilities to use superposition – to put bits of information into more than one state at the same time – and its restating of mathematical problems in terms of a Hamiltonian – which is essentially the energy of the forces that move particles about.

It does this by manipulating the states of quantum bits (qubits) to set up the problem that needs solving through the use of couplers and programmable magnetic memory (PMM). Once the problem has been set up within the system, the D-Wave One then determines the answer by naturally evolving its system into its lowest-possible energy state.

This evolution into a lowest-energy state – or the 'ground state' – is key to the operation, as it highlights the avenue D-Wave has used in its system. Indeed, the reason why the computer is called a quantum *optimiser* is that it arrives at this energy ground state adiabatically (without the release or input of heat within the system). It does this by cooling its circuitry to 20 millikelvin (272.98 degrees Celsius/459.36 degrees Fahrenheit; near absolute zero) and building it out of a material known as superconductor. In doing this, the D-Wave One can create a direct passage from the initial programmed system state (ie the problem) to the system ground state (ie the answer) naturally and incredibly quickly, considering a range of different permutations simultaneously.

In essence, the D-Wave One reaches answers to questions by 'tunnelling' through an energy landscape directly to the landscape's lowest-possible energy state. This can be likened to the passage of a golf ball on a golf course into a hole. The initial system's state is the golf ball on a tee, the energy landscape the hills and valleys of the course, and the hole the ground state. To reach the hole (the answer) in a classical computer, the system – non-adiabatically – moves the ball over the obstacles into the hole. In the D-Wave One, meanwhile, the ball tunnels through the hills and over the troughs directly into the hole.

The D-Wave One is already demonstrating the immense possibilities of quantum computing, but it's clear that there's still a lot more potential to revolutionise computing.

The statistics...

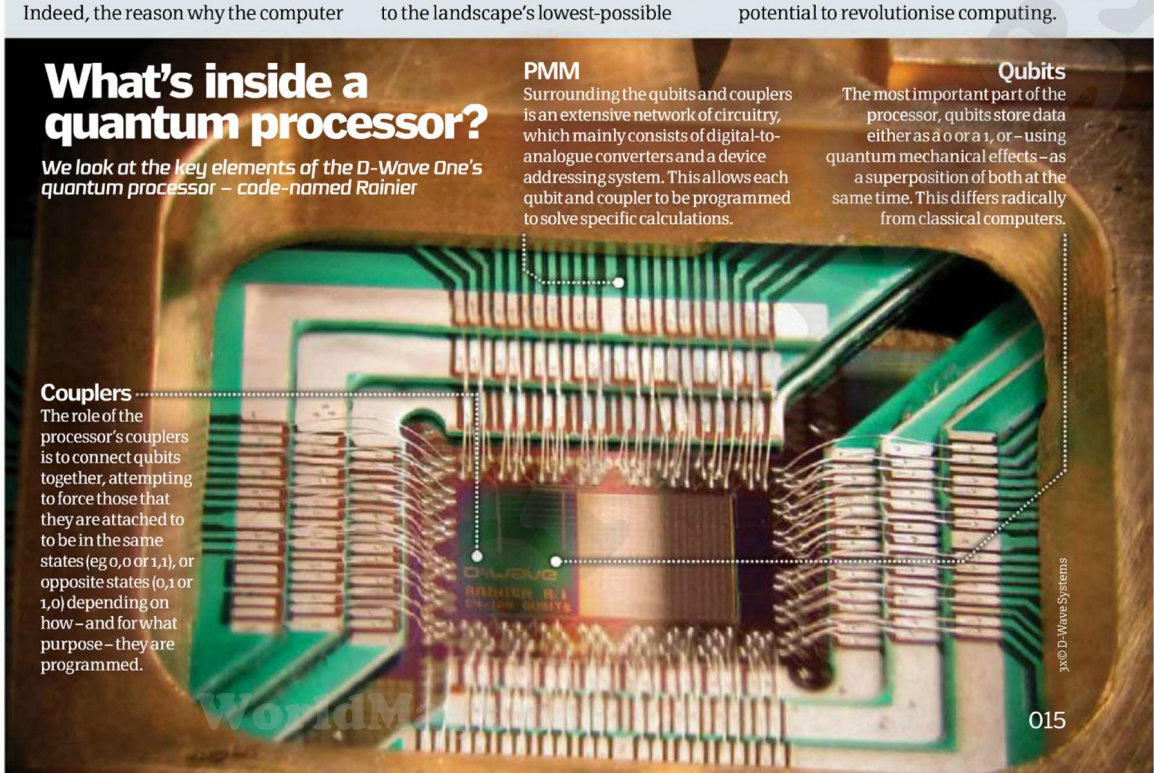


D-Wave One

Material: Superconductor
Qubits: 128
Couplers: 352
Junctions: 23,360
Temperature: 20mK (272.98°C/459.36°F)

What's inside a quantum processor?

We look at the key elements of the D-Wave One's quantum processor – code-named Rainier



"While an F-35 gets from London to Rome in 55 minutes, the Falcon could do London to Sydney in 50"



A Falcon HTV separates from a Minotaur rocket to begin its re-entry phase

6

The Mach 20 hyperplane

The Falcon HTV obliterates the speed of sound tenfold and is capable of reaching – and exceeding – the 13,000mph mark

Let's run some numbers. Mach 1 – considered the speed of sound at standard sea level conditions – is 1,225 kilometres (761 miles) per hour. As such, Mach 1.6 – the maximum operating speed of the cutting-edge F-35 Lightning II fighter jet – is roughly 1,930 kilometres (1,200 miles) per hour, a speed that would get you from London to Rome in just under 55 minutes. That's pretty fast, wouldn't you agree? Especially considering the standard passenger jet takes almost three times that to make the very same trip.

Wrong! Actually, it's not fast at all. In fact, when you place the Falcon HTV into this little competition, it makes both the F-35 and the passenger jet look like the Wright Flyer on its first wobbly test-flight.

Why? Once again the numbers reveal all. The Falcon hypersonic test vehicle (HTV) has been engineered to travel at speeds of Mach 20 and above – Mach 20 equating to roughly 20,900 kilometres (13,000 miles) per hour. As such, while that F-35 gets from London to Rome in 55 minutes, on the Falcon, you could hop across the Earth from London to Sydney, Australia, in 50 minutes.

All this comes courtesy of a programme dedicated to advancing humankind's understanding and critical knowledge of the technologies needed to generate a vehicle capable of sustained hypersonic flight. The HTV project – which at this time has consisted of both the HTV-1 and HTV-2 aircraft – is achieving these goals via a series of test vehicles that, once carried to orbital speeds on the back of a Minotaur IV Lite rocket, are released to accelerate up to – and over – 20,900 kilometres (13,000 miles) per hour.

The role these vehicles then play is best described as large data trucks – full-scale hypersonic aircraft equipped with a host of sensors to collect data during the high-speed operating envelope. This information, which includes feedback on the aircraft's aerodynamics, aerothermal effects, critical guidance and navigation and control mechanisms is then relayed in real-time back to DARPA (the Defense Advanced Research Projects Agency) for processing and analysis. The end goal of all this hypersonic flight and data acquisition is to attain a level of competency in which an armed hypersonic fighter aircraft can be built that could strike any target anywhere on the planet in less than two hours.

So far, the Falcon HTV vehicles have returned a swathe of hypersonic flight information. This includes verification of the test vehicles' reaction control system (RCS), hypersonic communication system, GPS – an amazing feat considering that the Falcon can be travelling at over 5.8 kilometres (3.6 miles) per second, and the necessary thermal-protective material properties needed for travelling at these immense speeds in the Earth's atmosphere.

The statistics...



Falcon HTV

Height: Classified
Length: Classified
Weight: Classified
Max speed: >20,920km/h (>13,000mph)

2x © DARPA

The engineering icon

The Golden Gate Bridge defied what was conceived as possible to create a link between San Francisco and Marin County

When it was completed back in 1937 the Golden Gate Bridge boasted the longest suspension bridge main span in the world, covering 1,280 metres (4,200 feet). Not only this, but by traversing San Francisco Bay, this marvel defies notoriously high wind speeds, blinding fog, powerful tides, a channel depth of 113 metres (372 feet) and a lot of difficult terrain. Indeed, for these reasons, it is not surprising that commentators at the time of its conception stated it was an impossible venture.

Naysayers aside, it did conquer the strait and since it has linked San Francisco to Marin County. This was achieved by three main factors: the choice of bridge type; the materials used; and advanced (for the time) construction techniques.

The bridge's design is a suspension, truss arch and truss causeway variant. The suspension element is key to its ability to sustain a 1,280-metre (4,200-foot) main span without support, with two towers taking its massive 123,000-ton load via two main cables. The cables are connected to each end of the bridge – and intermittently along its span via finer vertical cables – into each side of the strait via huge concrete braces; each main cable comprises 27,572 strands of steel.

The truss arch and causeway both deliver flexibility in terms of the main span's ability to move. This is very important considering the weight and shifting nature of its load (ie a varying number of moving vehicles) and also the differing temperature conditions; indeed, the main span can move vertically through five metres (16 feet) due to thermal expansion. This is why the main span is arched towards a central apex, a shape that accounts for this motion and ensures the structure remains stable at all times.

Lastly, the Golden Gate Bridge remains a great engineering feat due to its advanced construction techniques. The adoption of new advances in metallurgy means it not only features galvanised and carbon steel (both main cables are made from the latter), but is also coated with a lead-based primer and topcoat and, later, a zinc silicate primer and vinyl topcoat to mitigate against rust.

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5 TOP FACTS
THE GOLDEN GATE BRIDGE

Ferry inconvenient
1 Before the Golden Gate Bridge was built the only way to cross from San Francisco to Marin County was by boat. A regular ferry service began in the 1840s.

Naysayers
2 Prior to the bridge being built, many commentators stated it would be impossible to do so, with the strait too deep and its winds too fierce for any passage to be practical.

Maintenance
3 Today, a large team of 38 painters are permanently employed by the bridge's operators to maintain its paintwork, patching up areas that become heavily corroded by the sea air or otherwise damaged.

Fool's gold
4 The bridge's distinctive colour is a shade of vermilion called 'international orange'. It was chosen to complement the natural surroundings and enhance its visibility in fog.

Big birthday
5 The Golden Gate Bridge celebrated its 75th birthday on 27 May 2012, on which it played the starring role in a city-wide festival, in a nod to the Golden Gate Bridge Fiesta of 1937.



7

The Golden Gate Bridge close up

We analyse the key components of the planet's most iconic bridge



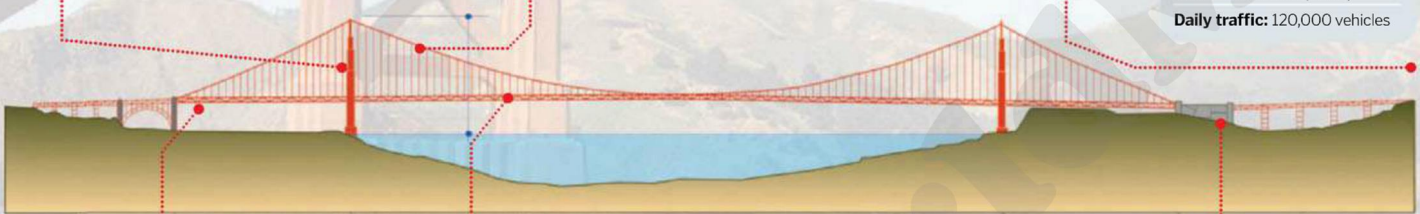
Towers
The towers soar 227m (745ft) above the water and 152m (499ft) above the roadway. Each takes a load of 61,500 tons from the cables.

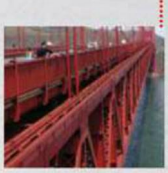


Cables
The roadway and walkway are suspended by two huge cables that pass through the bridge's two main towers. Each cable is made up of 27,572 strands of wire.



Gates
Entrance to the bridge is free on the northbound carriage, but southbound traffic pays a toll. Motor vehicles pay $6, while vehicles with more than two axles pay $2.50 per axle.





Walkway
Down either side of the roadway are civilian walkways, which are separated from the passing traffic by a reinforced steel barrier.



Roadway
The bridge is a truss arch and causeway design. As such, the roadway is curved towards a central apex so it can adapt to both the temperature and the variable weight of traffic.



Braces
Due to the immense weight of the roadway, the supporting cables are tightly locked within gigantic concrete braces located at either end of the structure.

The statistics...



Golden Gate Bridge

Material: Steel
Height: 227.4m (746ft)
Length: 2.7km (1.7mi)
Width: 27.4m (90ft)
Clearance: 67.1m (220ft)
Daily traffic: 120,000 vehicles

"The structure is built around a three-layered concrete and steel core"

The Shard explained

Designed to resemble a fragment of glass, how was this unique skyscraper built?

The Shard is a brand-new 310-metre (1,017-foot)-high skyscraper located on London's South Bank. It was designed by famed Italian architect Renzo Piano to simulate a shard of glass, and as such demanded some highly advanced construction techniques and equipment.

The skyscraper's structure is built around a three-layered concrete and steel core, which resembles a narrow step pyramid. This extends from the base of the tower and its array of steel pilings – driven deep into the earth as foundations – right up through the centre of the structure to the 72nd floor, where it is capped to accommodate a 500-ton spire. Surrounding the central core is a steel lattice from which the building's floor space is constructed on each level. The offices, rooms, galleries and facilities of The Shard are then covered with a total of 11,000 glass panels, which form the 56,000-square-metre (602,800-square-foot) reflective shell seen from the exterior.

Due to the height of The Shard – topping out at 310 metres (1,017 feet) – a total of five tower cranes were used to build it, with four of those 'jumping'. This process involves raising a crane by inserting an additional section during construction, with each crane once extended braced to the side of the building for stability. It was this technique that enabled the skyscraper's 66-metre (217-foot) spire to be winched up to the cap and then attached securely. Including this spire, The Shard is now the highest building in the European Union.

The base of the tower is built into a concourse area, extending from The Shard's ground floor into the London Bridge Quarter, a new plaza that links it with its sister building, The Place, as well as underground rail links and an above-ground bus terminal.



An average of three floors were added to The Shard every two weeks during construction

2x© Alamy

The Shard storey by storey

We look at this skyscraper's wide variety of facilities and amenities

Residences

Ten residences are located between the 53rd and 65th storeys, taking up a total of 5,760m² (62,000ft²). Each of the apartments offers stunning 360-degree views of London.

Hotel

Floors 34-52 are taken up by the five-star Shangri-La Hotel and spa, a 17,840m² (192,000ft²) development that will have 195 rooms and a swimming pool with views over the city.

Gallery

The highest public observation galleries in London are located between the 68th and 72nd floors, covering a total of 1,394m² (15,000ft²). They were opened in February 2013.

The statistics...

The Shard

Cost: £450m ($702m)
Start date: March 2009
Completion date: July 2012
Height: 309.6m (1,015.7ft)
Total floors: 95
Floor area: 110,000m² (1.2 million ft²)
Glass panels: 11,000
Glass area: 56,000m² (602,779ft²)
Elevators: 44
Escalators: 8

Offices

The bulk of The Shard is a series of offices, which will occupy floors two through to 28, over 55,280m² (595,000ft²). These are connected to the skyscraper's winter gardens.

Concourse (not shown)

The lowest levels, which make up 465m² (5,000ft²) are dedicated to retail and transport. The Shard sits in the heart of the new London Bridge Quarter, which features its own train and bus stations.

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1. CLASSIC

Eiffel Tower
The 7,300-ton, 324m (1,063ft) tall tower was designed by and named after Gustave Eiffel. It was the tallest man-made structure until 1930.



2. SYMBOLIC

Statue of Liberty
The 93m (305ft) tall, torch-bearing statue opened in 1886 to visitors who can sightsee from the crown of the statue.



3. ICONIC

Sydney Opera House
After 30 years of planning and building, this was finally opened in 1973. Its unique shell-like roofing has made it an icon of Australia.

DID YOU KNOW? *It takes 500W to rotate the London Eye fully loaded with 800 people. That's the power used by six light bulbs*

The EDF Energy London Eye

A world-famous landmark that casts an iconic eye over London

The London Eye was designed to celebrate the arrival of the millennium. It took seven years to design and build and opened to the public on 9 March 2000.

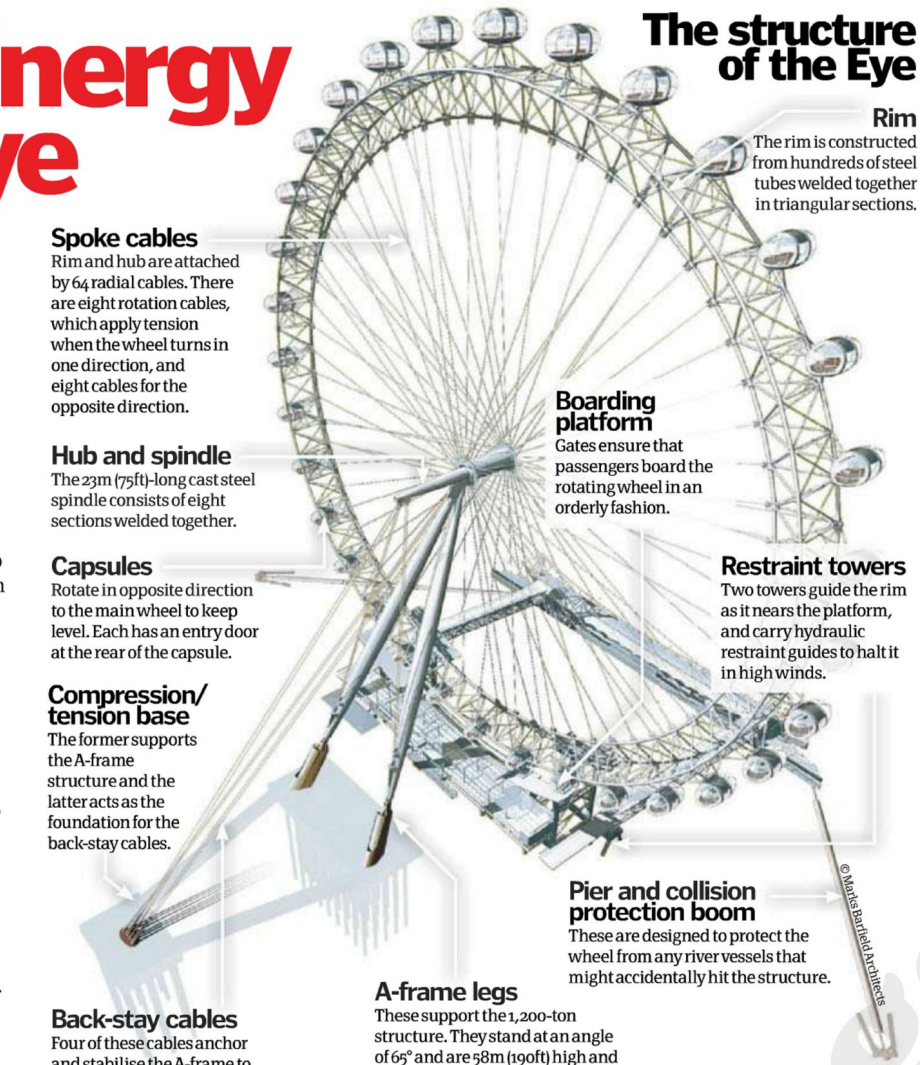
The Eye was such a unique engineering task that different parts of it were built throughout Europe. The capsules were built in France, the main structure in Holland, the cables in Italy, the hub and spindle in the Czech Republic and the rim bearings in Germany.

The whole wheel was assembled horizontally over the River Thames, next to Jubilee Gardens. The riverbed had to be surveyed in detail before work platforms could be put in place and they had to make sure they didn't disrupt any river traffic. The rim was built in large sections that were floated up the Thames on barges. The height of the river had to be monitored, to ensure that they could pass under any bridges on the way to the construction site.

Europe's largest floating crane, the Taklift 1, lifted the sections from the barges onto the work platforms, where they were attached to the hub and spindle by steel cables. The A-frame legs of the structure are set in 33m (108ft)-deep concrete foundations and are hinged at the base. Once the main A-frame was fixed to the hub and spindle, the hinges allowed the whole 1,900-ton structure to be lifted into its vertical position. It took a week to lift the wheel in several stages into its present position. Tension cables set in 1,300 tons of concrete foundation were used to anchor the wheel in place. Capsules were then fitted to the outside of the rim.

The rim is rotated by sets of standard lorry tyres powered by hydraulic motors. As the wheel turns in one direction, the capsules have their own motors to slowly rotate them in the opposite direction to keep them level.

The structure of the Eye



Rim
The rim is constructed from hundreds of steel tubes welded together in triangular sections.

Spoke cables
Rim and hub are attached by 64 radial cables. There are eight rotation cables, which apply tension when the wheel turns in one direction, and eight cables for the opposite direction.

Boarding platform
Gates ensure that passengers board the rotating wheel in an orderly fashion.

Hub and spindle
The 23m (75ft)-long cast steel spindle consists of eight sections welded together.

Capsules
Rotate in opposite direction to the main wheel to keep level. Each has an entry door at the rear of the capsule.

Restraint towers
Two towers guide the rim as it nears the platform, and carry hydraulic restraint guides to halt it in high winds.

Compression/ tension base
The former supports the A-frame structure and the latter acts as the foundation for the back-stay cables.

Pier and collision protection boom
These are designed to protect the wheel from any river vessels that might accidentally hit the structure.

A-frame legs
These support the 1,200-ton structure. They stand at an angle of 65° and are 58m (190ft) high and 20m (66ft) apart at the base.

Back-stay cables
Four of these cables anchor and stabilise the A-frame to its concrete base.

© Marks Barfield Architects



Passenger capsules

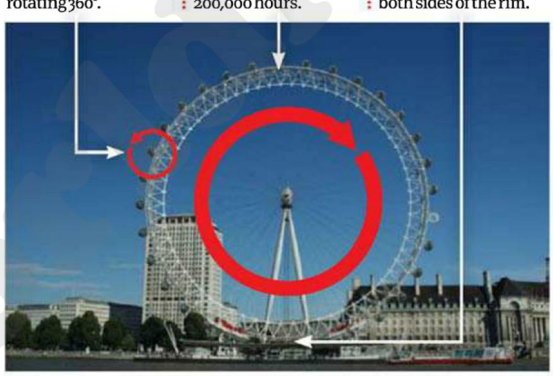
1. Circular rings are attached to the outside rim of the wheel.
2. The rings contain a circular-toothed rail.
3. An underfloor motor drives the toothed rail to keep the capsule level as it rotates.
4. The 32 panels of glass on each aerodynamically shaped capsule consist of two sheets of 6mm (0.24 in) glass that sandwich a layer of high-strength clear plastic.
5. The capsules contain their own temperature and air conditioning systems.
6. Each capsule is fitted with camera and radio links to the ground.

Rotation of the Eye

Capsules
The toothed wheel of the drive motor engages with the circular rails that surround the capsule, rotating 360°.

Main wheel
The wheel rotates round the hub, which consists of two rings of roller bearings with a lifespan of some 200,000 hours.

Driving the rim
Four sets of drive units consist of four lorry tyres. They grip either side of the flat running beam that runs along both sides of the rim.



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"With a full audience the reverberation time is approximately 2.2 seconds"

Sydney Opera House acoustics explained



How does the Concert Hall inside this famous landmark disperse sound so well?

The Sydney Opera House's Concert Hall still remains to this day one of the premiere destinations for concerts and recitals in the world, thanks in the main to its fantastic acoustics.

The Concert Hall has a very distinctive geometric design. Similar to a cathedral, the auditorium has an incredibly high vaulted ceiling, a long, stepped main seating array, raised organ platform, recessed sound stage, plus an elevated, staggered gallery. This layout, especially aided by the high ceiling, grants sound within the hall a bright quality with strong reverberation; with a full audience the reverberation time is approximately 2.2 seconds from 100 to 8,000 Hertz.

Complementing the geometric layout are the hall's construction materials, which – ranging from the smallest to the largest aspect – were picked specifically to improve sound quality and dispersal. The walls and floors are made of laminated Australian brush box, the ceiling from white birch, while much of the ceiling's crown is crafted from sculpted plywood. The extensive use of wood offers excellent control of everberation and echo as well as generating a softer reproduction of sounds. In addition, each chair is made from white birch and lined with wool, the latter material providing excellent noise absorption at the critical point of contact.

Finally, the hall sports a unique feature: a fully height-adjustable canopy directly above the sound stage. This canopy comprises of 18 doughnut-shaped acrylic rings that extend down from the ceiling and redirect sound waves that emanate directly up from the stage to other more beneficial areas of the room. This helps with the hall's lack of early sound wave reflections due to its height, and also maintains the auditorium's geometry.

Key acoustic features

We explore the Sydney Opera House's Concert Hall to see how sound travels to every corner

Clouds

18 doughnut-shaped acrylic rings, or 'clouds', hang above the sound stage. These are used to reflect sound into more beneficial areas of the hall and back to the stage.

Angles

The surfaces immediately to the side of the stage are angled away and down into the seating area. These angles are used to prevent sound from bouncing back and forth across the room, which would create distortion.

Wood

The hall's walls and floor are made of laminated Australian brush box. This material is used as it does not just reflect sound, but resonates slightly, granting it a much softer quality.

Wool

All the seats are lined with wool. This is used as the material is especially good at absorbing sound and, as the seats are the point of destination, stop it from rebounding and distorting.

© Getty Blain Woon Tee Yap; Robyclark

5 TOP FACTS
TALL TOWERS

1 Skytree Tower
At 634 metres (2,080 feet), Skytree is the second tallest structure in the world after the 830-metre (2,723-foot) Burj Khalifa skyscraper in Dubai, United Arab Emirates.

2 Canton Tower
Constructed in time for the 2010 Asian Games, the Canton Tower reaches 600 metres (1,968.5 feet) into the sky, making it officially the tallest structure in China.

3 CN Tower
This 553-metre (1,814-foot)-tall concrete tower was opened to the public in Toronto, Canada, in 1976. For 34 years it was the tallest manmade structure on the planet.

4 Ostankino Tower
For a period of nine years, this 540-metre (1,772-foot)-tall tower, located in Moscow, Russia, was the tallest in the world – until the construction of the CN Tower.

5 Oriental Pearl Tower
Located in Shanghai, China, at 468 metres (1,535 feet) tall the Oriental Pearl Tower easily dwarfs the 324-metre (1,063-foot) apex of the well-known Eiffel Tower.

DID YOU KNOW? *Elevators take visitors to the Skytree's observation decks at around 10m (33ft) per second*

Building the Skytree Tower

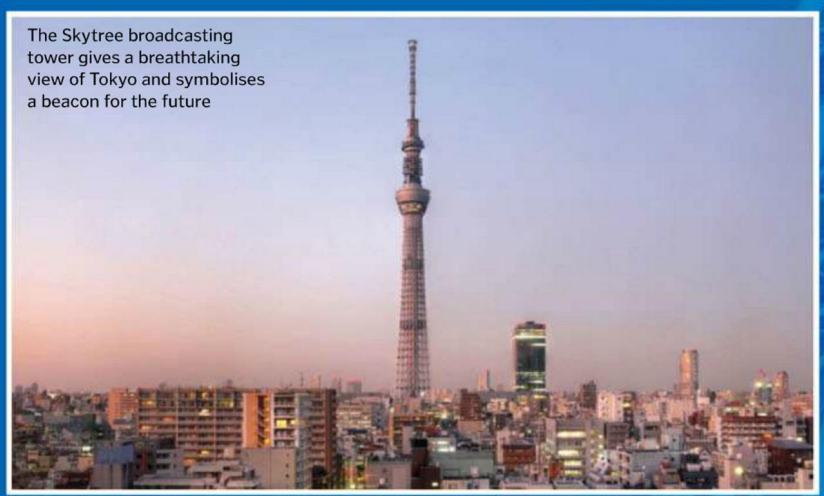
Discover everything you need to know about the tallest freestanding broadcasting tower in the entire world and learn how it was built

Towers like the Skytree in Tokyo, Japan, are distinct from skyscrapers, as they are not primarily built to contain apartments or offices. In the case of the Skytree, it was built to provide a high enough structure to transmit digital terrestrial broadcasting to all of central Tokyo.

The foundations consist of 35 and 50-metre (115 and 164-foot)-deep steel and concrete, wall-like piles that support an equilateral triangle, with each side measuring 68 metres (223 feet) long.

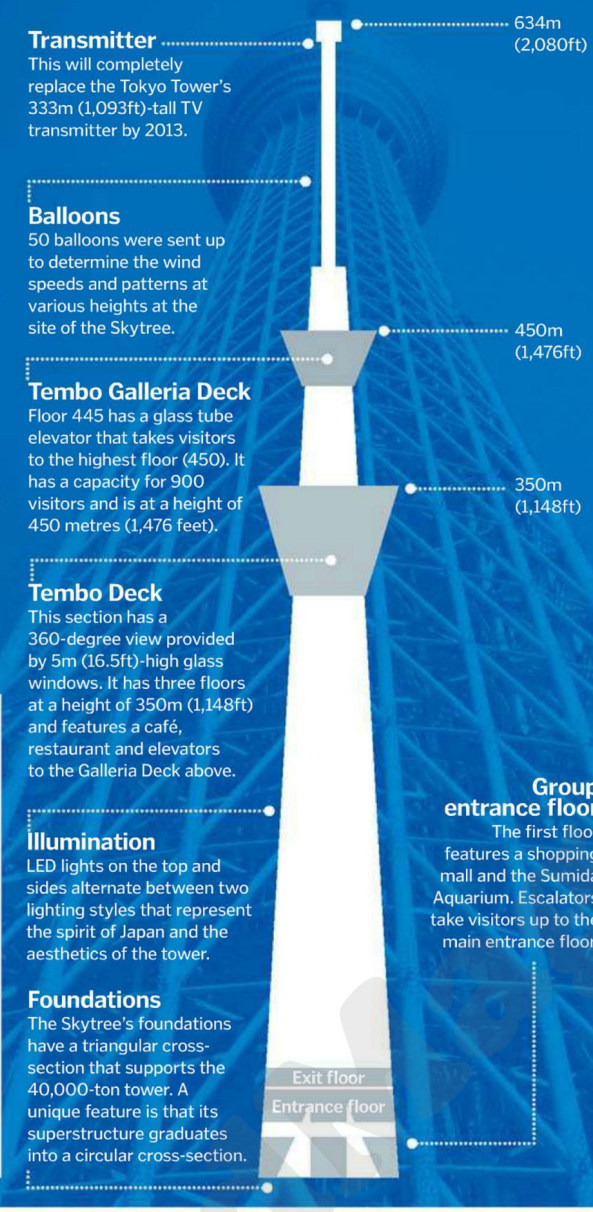
At a height of 320 metres (1,050 feet) the lattice of trusses gradually tapers into a full circle. At the tower's core is a reinforced concrete column that rises to a height of 125 metres (411 feet) and is attached to the 2.3-metre (7.5-foot)-diameter tubular trusses with steel beams. This section of the tower remains rigid while the sections above it are flexible to withstand the impact of seismic and climatic activity.

Above 375 metres (1,230 feet) there are two ballast weights that are attached to the outer structure with dampers and huge 907-kilogram (2,000-pound) spring coils. Together these act as a tuned mass-damping system to reduce lateral movement caused by high winds that lash the top of the tower.


The Skytree broadcasting tower gives a breathtaking view of Tokyo and symbolises a beacon for the future

Tokyo Skytree key floors

We scale the planet's biggest tower, revealing what you can find from the base to the very tip



How Skytree measures up



Earthquake precautions

To cope with earthquakes, the flexible section of the tower consists of a central pillar connected to the outer steel structure with oil shock absorbers. This makes the inner and outer sections structurally discrete, so when strong winds or quakes hit the building they move in opposing directions. Incredibly, by dissipating the seismic energy, the oil damping system reduces this swaying by up to 50 per cent. The system was put to the test when the Great East Japan Earthquake struck the building, while under construction, on 11 March 2011. The 9.0-magnitude quake caused the top of the then 625-metre (2,051-foot)-high tower to sway about six metres (19.5 feet), but it still came away unscathed.

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MEGA skyscrapers

Discover the engineering tech behind humankind's biggest buildings as we track the rise and rise of the skyscraper

The statistics...

Kingdom Tower

Height:
>1,000m (>3,280ft) TBA

Floor count: 157

Building use:
Apartments and offices

Construction dates:
December 2011-2017 (expected)

Architect: Adrian Smith

Area:
3,530,316m² (38 million ft²)

Eventual status:
Tallest building in the world



© Adrian Smith & Gordon Gill Architecture; SPL

5 TOP FACTS
NATURE ON A HIGH

Highest land point
1 Mount Everest is nature's tallest edifice at a skyscraper-dwarfing 8,850m (29,035ft). It has been ascended over 5,100 times and claimed over 220 lives in the process.

Tallest peak
2 Mountains tend to be measured from sea level but, strictly speaking, the world's tallest peak is Hawaii's Mauna Kea, which rises 10,203m (33,476ft) from the Pacific Ocean floor.

Tallest tree
3 Discovered by two hikers in 2011, a Californian redwood named Hyperion measures 116m (379ft). It stands in an undisclosed location in Redwood National Park, CA.

Highest flyers
4 The world's highest-flying animals are Ruppell's vultures, capable of cruising at 6,096m (20,000ft), although bird strikes on jets have occurred at over 10,668m (35,000ft).

Highest flyers 2
5 Six nations have put animals into orbit, including US chimp, Ham, in 1961. In 1968, Russia's Zond 5 probe returned from the moon carrying a payload of tortoises, flies and worms.

DID YOU KNOW? *The Kingdom Tower was planned to be a mile high, but this was soon abandoned after analysis of the terrain*

Today, they are often seen as symbols of national and civic pride as well as a key solution to urban overcrowding. Yet the skyscraper as we know it only came into being in the late-19th century, not through the ambition of architects but through a combination of contemporary engineering techniques and materials that finally triumphed over the builder's age-old enemy: gravity.

For most of history, the tallest man-made structure on Earth was the Great Pyramid of Giza, at 146 metres (479 feet) – a height that would barely qualify as a skyscraper today. The reason was simple: because all buildings were constructed from bricks and mortar, they were all built to the same principle: the higher the building, the bigger the base. All that changed though with the Industrial Revolution and the ability to construct ever stronger and longer iron and steel girders. Suddenly, buildings could be taller without having to take up so much space at ground level, sparking a 'space-race' that culminated in today's tallest and most talked-about buildings (see 'Top of the world' box).

Skyscrapers are a monumental challenge to both design and construct. Winds can cause them to sway, earthquakes can shake even the strongest foundations, fires can melt through steel cores and, as skyscrapers begin to approach the edges of thinner, colder air, living conditions must be adapted to compensate. For all these reasons, building skyscrapers remains a constant test of human ingenuity against natural forces.


An artist's impression of the One World Trade Center as part of the Manhattan skyline

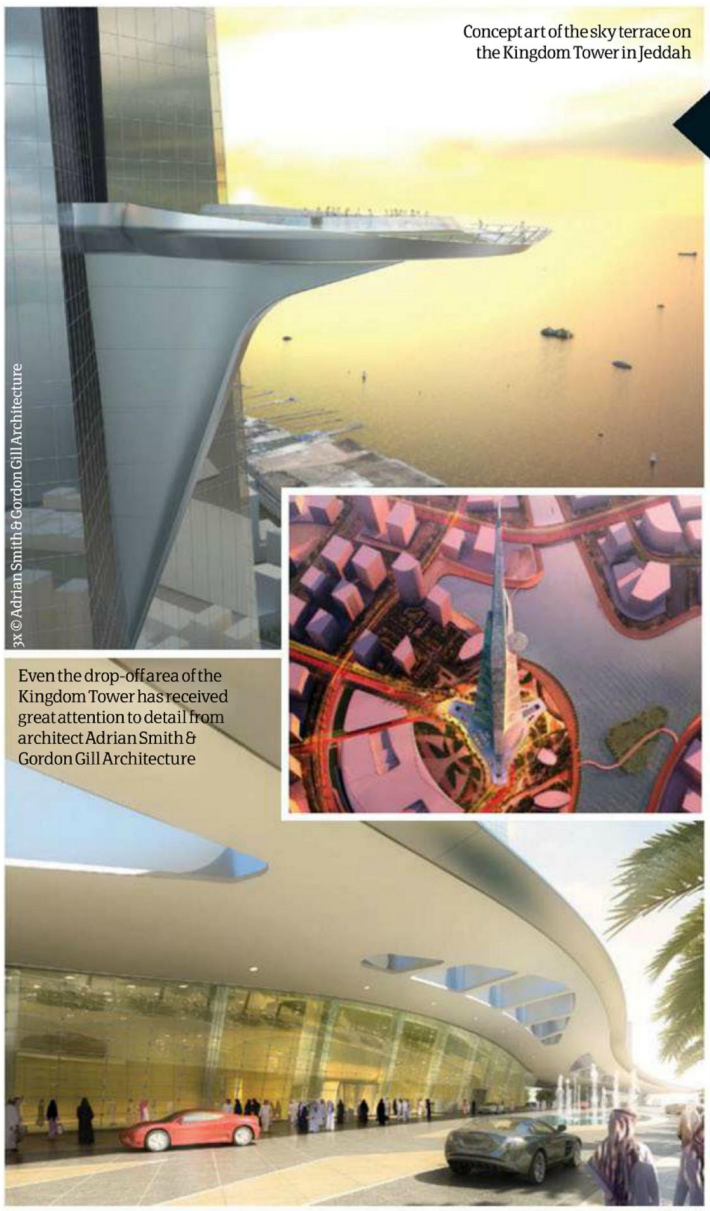
© Silverstein Properties, Inc/dbox

Designing a skyscraper requires the combined efforts of hundreds of skilled professionals and thousands more to construct, usually to strict deadlines. It starts with planning; these days involving lengthy computer-aided design processes that must factor in everything from ground conditions and load and stress testing, health and safety guidelines and emergency evacuation procedures.

Once construction begins, attention focuses around a steel skeleton called the superstructure – a collection of vertical columns and horizontal girders that run through the building. This concentrates the downward force of gravity into a relatively small area at the base, transferred through the substructure – a series of steel columns, plates and springs, underpinned by reinforced concrete, that extends far underground. This allows the building's concrete and glass exterior, or curtain wall, to reach higher by effectively only having to support its own weight. Ultimately, however, the whole structure rests on clay, making the foundation just as important as the visible structure that rises above it.

It is the superstructure that has to cope with the most strain. For the first skyscrapers – which rarely exceeded ten storeys – iron was used, but throughout the 20th century when the US ruled the world of high-rise construction, steel became the material of choice. Superstructures used to resemble a series of steel boxes containing both horizontal and vertical supports throughout to spread the load. However, as skyscrapers grew taller, the distance between these supports decreased, reducing available floor space (a vital consideration) as well as increasing weight. In the mid-Sixties, a new tubular design emerged based around interconnected exterior columns, reducing the number of interior columns required. It was this design that enabled the original World Trade Center and other record-beating structures to be made.

For nearly 150 years, modern skyscrapers have been built to inspire shock and awe, relying on ▶


Concept art of the sky terrace on the Kingdom Tower in Jeddah

3x © Adrian Smith & Gordon Gill Architecture

Even the drop-off area of the Kingdom Tower has received great attention to detail from architect Adrian Smith & Gordon Gill Architecture

Kingdom of the skies

At over 1,000 metres (3,280 feet) – the precise height still remains a closely guarded secret – Jeddah's Kingdom Tower will be nearly twice as tall as the US's tallest (the Willis Tower) and over 200 metres (656 feet) higher than the world's current leader: the UAE's Burj Khalifa.

Construction began in December 2011, after long delays and heated debate. Earmarked for offices and luxury apartments, some have questioned who exactly will be able to afford to live there. For example, the majority of Burj Khalifa's apartments are reportedly still empty after property prices plummeted, while other high-profile Middle East developments such as Dubai's artificial island complex, The World, are viewed as little more than follies in the current economic downturn.

Then again, skyscraper design has always been as much about prestige as practicality. Four buildings have been called 'world's tallest skyscraper' in the past 12 years – at an average cost of $1.2 billion – yet all have attracted significant interest and publicity for their host cities. The project's backers remain confident that the Kingdom Tower will transform Jeddah's reputation as a cultural and economic centre, much as the Petronas Towers did for Kuala Lumpur, Malaysia. Expect the outcome some time in 2017.

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The rise of skyscrapers

"Four buildings have been called 'the world's tallest skyscraper' in the past 12 years"



The Burj Khalifa – currently the world's tallest building – took six years to construct

On solid ground

Long before a skyscraper takes shape, the foundation has to be planned and excavated. First the ground must be surveyed, taking into account not just its composition but also the likelihood of earthquakes, which can be compensated for by installing seismic dampeners. A pit is then dug which can extend up to five floors, into which vertical piles or reinforcing rods are sunk, securing the substructure into the bedrock. Typically this substructure is made up of vertical columns resting on cast-iron plates, which sit on top of a grillage of horizontal steel beams. The substructure spreads out like a pyramid below the ground, distributing the enormous weight, and is encased in concrete. Only once the foundation and substructure are complete, can the superstructure be lifted and secured onto it, allowing the rest of the construction to begin.

eye-catching designs and ever-higher altitudes to attract tenants, businesses and visitors. In technical terms, there is no reason why skyscrapers could not reach three or even five kilometres (two to three miles) and, with commercial airliners cruising above eight kilometres (five miles), they have little to fear from accidental collision – although since 9/11 the public has understandably less confidence in such assurances.

Indeed, it is the threat of terrorism that poses the biggest obstacle to the continued dominance of the skyscraper. Ever since the Twin Towers collapsed from the top down and inside out, architects have been forced to go back to the drawing board about how skyscrapers should be designed and the kind of events they should be built to withstand. Nowhere is this felt more keenly than in the One World Trade Center, due to open on the Ground Zero site in 2013. Featuring not only a 57m (187ft) windowless concrete base but also 0.9m (3ft) reinforced concrete walls for stairwells and elevator shafts, windows made of blast-resistant plastic on one side of the building, dedicated stairwells for firefighters and a ventilation system including biological and chemical filters, safety and security now lie at the heart of this highly symbolic mega structure.

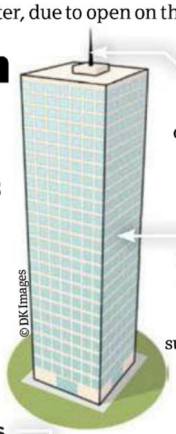
So, with the continuing risks involved in containing so many people in a single exposed building, as well as the escalating costs of building them, will future generations still idolise the skyscraper or is this just a new challenge to man's 4,000-year obsession with 'growing up'? Only time will tell...



The design of the One World Trade Center is highly focused on safety and security

Strength from within

What elements make up the core of a skyscraper?



© DK Images

Spire
An essential design element and therefore counted in the building's official height – as opposed to antennas, which are not.

Windows
External window panels are lowered into place as each floor is completed. They are made from super-toughened glass or, on occasion, blast-resistant plastic.

Beams and girders
Lattices of steel beams and girders give the superstructure strength, often covered with plaster, vermiculite and fibreglass to add corrosion and heat protection.

Curtain wall
With the superstructure bearing most of the load, the curtain wall of reinforced concrete and fire-resistant plaster mainly supports its own weight.

Ground floor
The skyscraper's heart, not least because of its reinforced stairways and elevators as well as the building's safety and security systems.

Elevators
Banks of elevators rise through the core of the building, making it fit for purpose. Scenic elevators may run along the exterior wall.

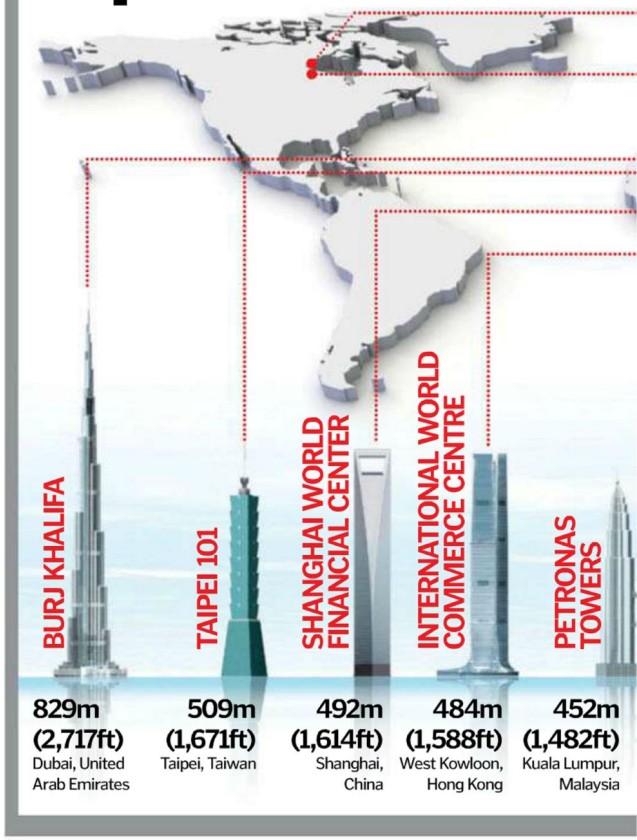
Grillage
A framework of steel beams and girders, providing a broad, strong and rigid core to the substructure.

Columns
Secured to the grillage by metal plates, up to 36 steel columns rise through the skyscraper's core and perimeter.

Bedrock
The layer of solid rock far beneath the surface soil, onto which the building must be secured by steel piles, riveted to iron plates.

Concrete
Alongside steel, reinforced concrete is the backbone of the skyscraper, not least to provide a solid, level base for construction to begin.

Top of the world Whe



WorldMags.net

HEAD 2 HEAD
NO EXPENSE SPARED



1. PRICEY

Burj Khalifa
Cost: $1.5 billion
The current tallest skyscraper was only the third most expensive to build. Falling property prices may mean this takes decades to recover.



2. PRICIER

Petronas Towers
Cost: $1.6 billion
With its twin towers linked by a sky-bridge, this set new records in 1998... until Taipei 101 came along.



3. PRICIEST

Taipei 101
Cost: $1.8 billion
The world's priciest skyscraper since 2004, thanks to the revolutionary construction procedures needed to build the 0.5km (0.3mi)-high structure.

DID YOU KNOW? *Skyscrapers are usually measured from ground-floor entrance to spire pinnacle*



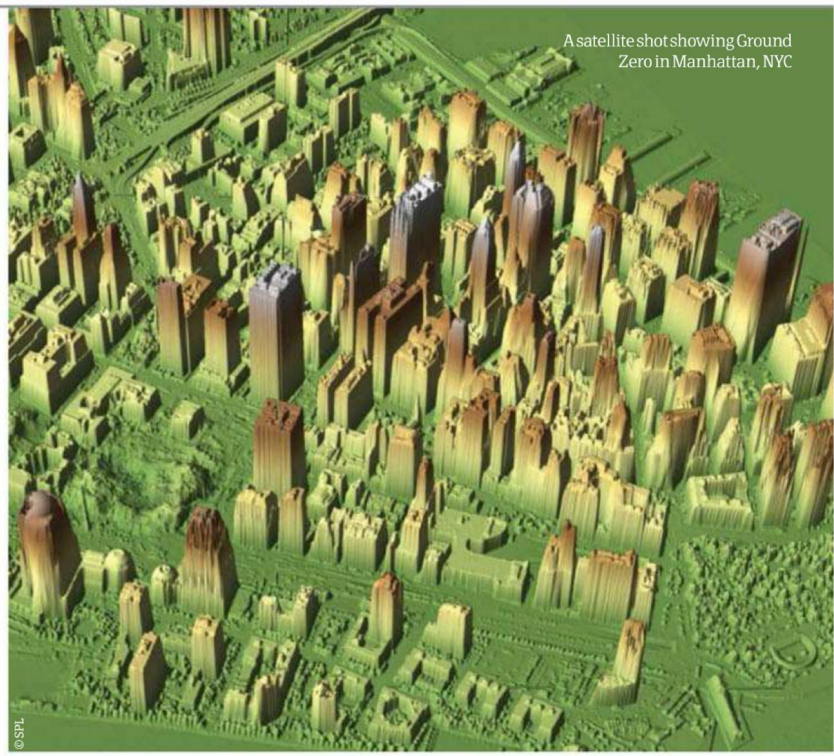
Material matters

Advances in skyscraper design have always gone hand in hand with improvements in construction materials, particularly the two key components of steel and concrete.

Concrete must be reinforced by pouring it onto a grid of steel rods, although smart fibres may also be contained within as well as carbon nanotubes, among the strongest materials known to man, to withstand the half-million ton or so's weight of materials and people resting on them. Meanwhile, concrete walls and internal skeletons have become progressively lighter, stronger and more fire resistant. Chilled, pressurised pumping procedures are also used to propel concrete to greater heights before setting.

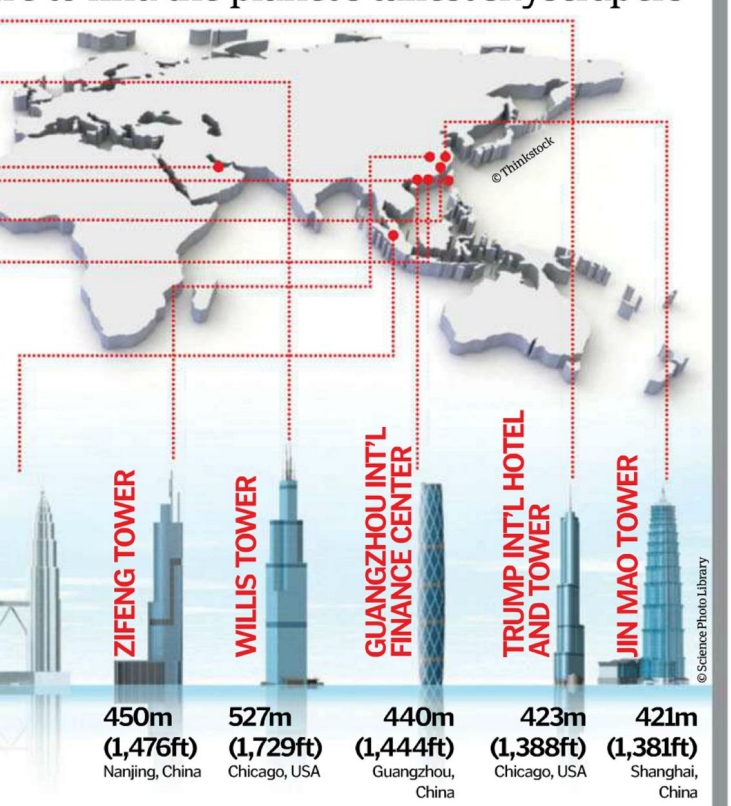
Even more important was the evolution of modern steel production and fabrication that made skyscrapers possible in the first place. From Englishman Henry Bessemer's (1813-1898) processes for mass-producing steel, to Fazlur Khan's (1929-1982) tubular steel superstructures that first enabled heights of over 500 metres (1,640 feet) to be reached, state-of-the-art steel remains the backbone of the modern skyscraper to this day.





A satellite shot showing Ground Zero in Manhattan, NYC

ere to find the planet's tallest skyscrapers

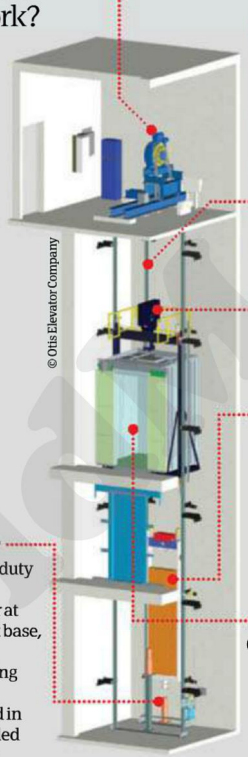


450m (1,476ft)	527m (1,729ft)	440m (1,444ft)	423m (1,388ft)	421m (1,381ft)
Nanjing, China	Chicago, USA	Guangzhou, China	Chicago, USA	Shanghai, China

Elevators

How do the lift systems in super-tall structures work?

A key contributor to the rise of the skyscraper was the elevator. Elisha Otis invented the first safety elevator in 1852, featuring a mechanism to prevent the car from crashing down if the cable broke. Normal, freight, express and even scenic elevators run through all areas of skyscrapers, although still focused on the highly reinforced central shafts. They contain two-way communication and safety systems to control speed, load capacity and door openings – as well as multiple cables in case one or more should snap. Without lifts, life for office workers and residents would be almost impossible.



Winch
Part of a motorised control mechanism situated above each elevator, responsible for raising and lowering the compartment. May or may not contain gears.

Rope
A traction steel cable capable of supporting the weight of a full compartment and counterweight. Typically, skyscraper elevators use four to eight ropes each.

Governor
A system of ropes, sheaves and pulleys connected to the compartment and shaft base, ensuring the elevator moves at a controlled pace.

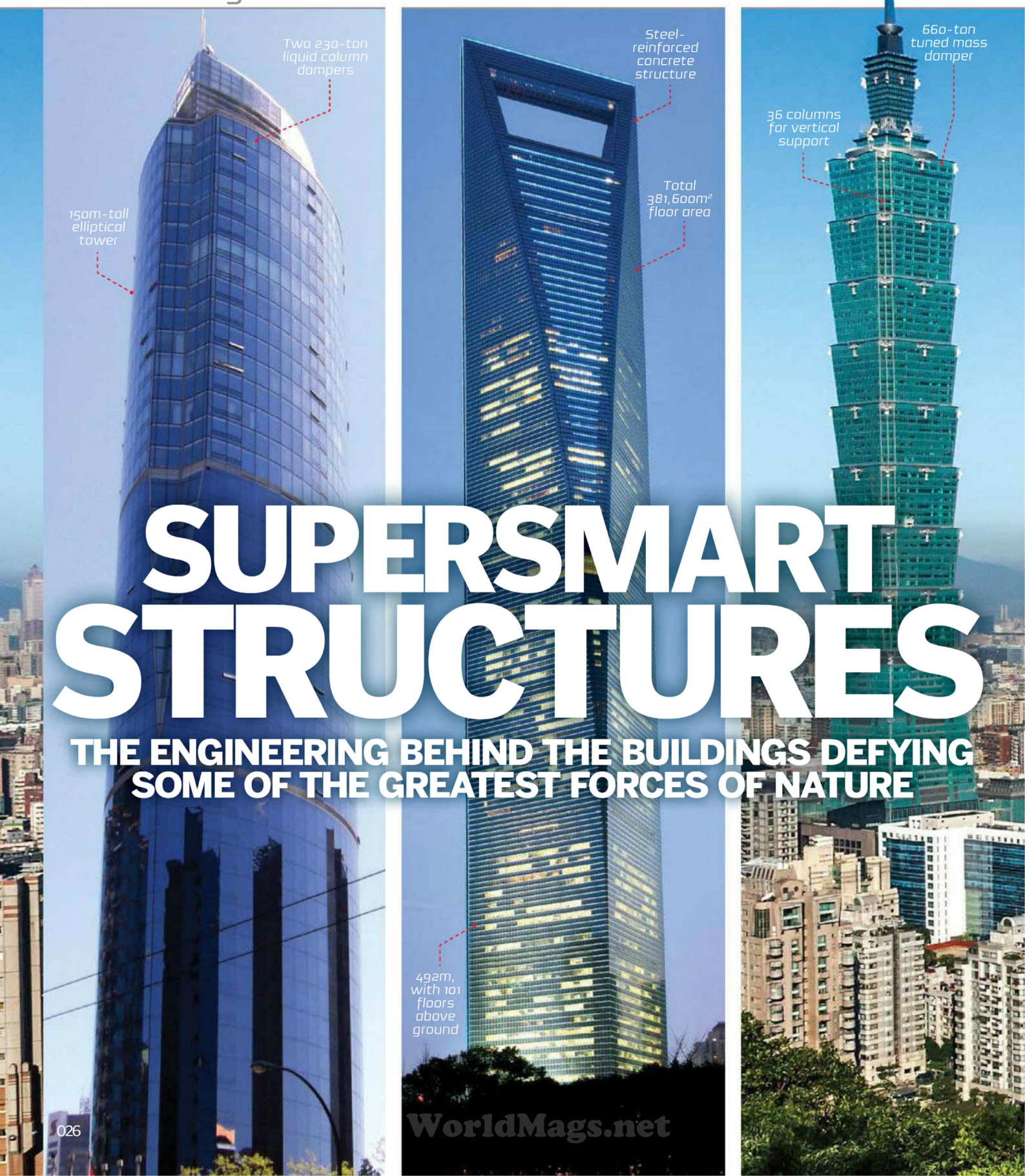
Counterweight
Reduces the load carried by the winches and motors. Counterweights and compartments run on guide rails to reduce speed should the rope snap.

Compartment
Capable of carrying around 12 people at about 2.5m (8.2ft) per second. It features sophisticated weight, speed and temperature sensors.

Buffer
A heavy-duty shock absorber at the shaft base, usually containing a piston mounted in an oil-filled cylinder.

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"A hostel made up of concrete blocks survived the 2011 Japan tsunami and an 89-foot boat"



SUPERSMART STRUCTURES

THE ENGINEERING BEHIND THE BUILDINGS DEFYING SOME OF THE GREATEST FORCES OF NATURE

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5 TOP FACTS
TOUGH BUILDINGS

1 Petronas Twin Towers
The Skybridge connecting the towers at the 41st and 42nd floors of this Malaysian landmark isn't fixed at either end. It slides in and out as the towers sway in the wind.

2 The Bubble Houses
This pair of dome houses in Florida were built in 1954 by architect Eliot Noyes. They use no wood or nails and their domed shape makes them great at resisting hurricanes.

3 US Bank Tower
The tallest building in California, this office block in LA is designed to withstand an 8.3-magnitude earthquake – larger than the San Andreas Fault can generate, in theory.

4 Nishiki Tower
A five-storey, tsunami-proof building in Japan, containing rescue equipment and space for evacuees to shelter. It could withstand an impact from a ten-ton ship!

5 County Records Building
Built in 1827 in Charleston, South Carolina, it's the oldest fireproof building in the USA. It's constructed entirely from solid masonry to protect the valuable county records.

DID YOU KNOW? *The Taipei 101 skyscraper can boast the world's fastest lifts; they travel at 60.7km/h (37.7mph)!*

After a tsunami hit Japan in 2011, a 27-metre (89-foot)-long boat was left perched on the roof of a two-storey building. Although almost every other nearby structure had been flattened, this particular building had survived both the wave and the weight of the vessel on top. It was a hostel in the town of Otsuchi, made of concrete blocks with a flat roof. When the tsunami struck, the water swept through the ground floor foyer and knocked down some of the walls, but the supporting corner pillars survived and the building stayed up. The houses around it were made of timber and the wave ripped them from their foundations.

In this modern version of *The Three Little Pigs* story the house with the best design is the one that stays upright. But in the 21st century, buildings have a lot more to contend with than hungry wolves. There are now nine buildings in the world that are over half a kilometre tall with more planned or currently under construction. At that height, winds cause skyscrapers to sway from side to side by up to two metres (6.6 feet) on the top floors. From below, earthquakes can vibrate the ground to such an extent it turns to quicksand, causing buildings to pull loose from their foundations and topple clean over. Fortunately today's architects have more than straw, sticks and bricks at their disposal...

Tackling tsunamis

A tsunami occurs when an earthquake lifts or drops a section of seabed. Although the vertical movement might be less than a metre (3.3 feet), it is many miles wide and involves billions of tons of water. Out at sea, tsunamis travel as fast, low waves, but when they reach the shore, the wave front can rise to 30 metres (98 feet), travelling inland for up to five kilometres (3.1 miles). Just two metres (6.6 feet) of water exerts enough pressure to destroy a brick wall, and boats, cars and debris carried with it strike buildings with the force of a wrecking ball. Buildings can also be destroyed as water scours away at the soil and undermines foundations.

Rather than trying to stop the water, tsunami-proof buildings present as little resistance to its flow as possible. The walls of the ground floor may be designed to fall down, while the upper storeys are supported by strong pillars at each corner – or the entire building may be on stilts. It is also more effective to place houses at a 45-degree angle with large gaps between them. Artificial reefs can absorb a lot of the wave energy before it hits land.

The statistics...

Tohoku Sky Village

Location: North-east Japan

Year constructed: Proposed

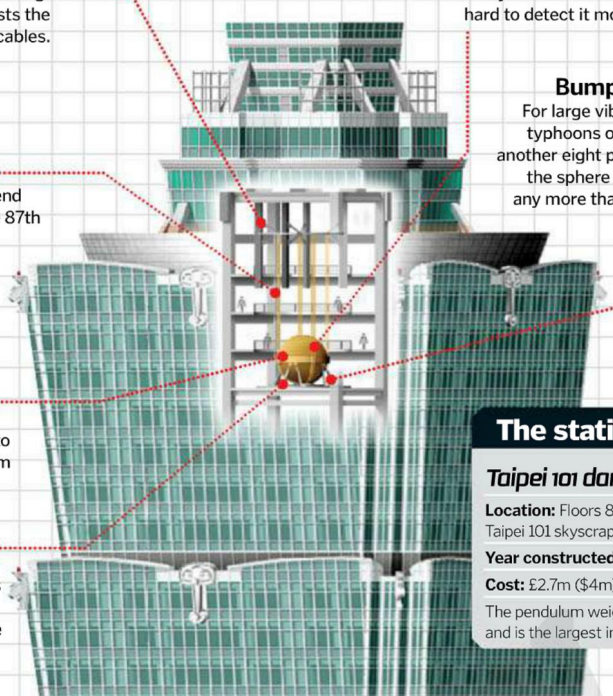
Cost: £160 million

SAKO Architects has designed a circular platform 20m (66ft) above sea level with room for up to 500 houses. If a tsunami strikes here, the whole village becomes an artificial island.

Counteracting the wind and ensuring nothing falls over...

Because they are anchored at the bottom and free at the top, tall buildings sway in the wind. Skyscrapers can defend against this by making themselves stiffer, but only up to a point as stiffer materials are more prone to cracking. Sometimes it is better to design the building with some flexibility and to avoid harmonic frequencies that could exaggerate the movement. Dubai's Burj Khalifa uses a deliberately irregular, stepped shape to break up wind vortices, while others like the Taipei 101 use tuned mass dampers – giant hydraulic pendulums hung near the top – that swing to counterbalance sway from the wind. Low-rise buildings aren't safe either. In a hurricane, pitched roofs act like an aerofoil as wind passes over them, sucking them upwards. Hurricane-proof houses use steel struts or cables that run through the walls to bind the roof to the foundations.

Taipei 101 in focus



Tuning frame
On the 91st floor, a support frame monitors building vibration and adjusts the movement of the cables.

Movement range
Normally, the sphere swings no more than 35cm (13.8in) every seven seconds and it's hard to detect it moving.

Bumper system
For large vibrations during typhoons or earthquakes, another eight pistons prevent the sphere from swinging any more than 1.5m (4.9ft).

Steel cables
Eight cables descend 42m (138ft) to the 87th floor. Each is 9cm (3.5in) thick and could support the mass damper by itself.

Mass block
41 steel plates are stacked together to form a sphere 5.5m (18ft) across.

Hydraulic dampers
Eight huge pistons absorb the energy of the steel sphere as it swings from its cables.

The statistics...

Taipei 101 damper

Location: Floors 87-92, Taipei 101 skyscraper, Taiwan

Year constructed: 2004

Cost: £2.7m ($4m)

The pendulum weighs 660 tons and is the largest in the world.

Fighting fire

Concrete and brick are both already fireproof, but buildings *made* of brick or concrete are not. A steel-framed building will collapse once flames reach in the region of 540 degrees Celsius (1,004 degrees Fahrenheit) because the steel becomes soft. Building fires can reach these temperatures quite quickly, feeding on nothing more than the furniture and fittings.

Sometimes the best solutions are surprisingly low tech. Ordinary plasterboard is made of the mineral gypsum, which has water chemically locked up within it. When it gets hot, this water is released as steam, which absorbs some of the heat from the inferno. Similarly, steel beams can also be protected by spraying them with a quick-setting gypsum mixture.

To prevent fire from spreading through cable ducting and access channels, we use something known as intumescent materials that swell when they are heated. Packed around a plastic pipe, for instance, an intumescent foam will pinch the pipe shut, sealing it.

The statistics...

Gotthard Base Tunnel

Location: Swiss Alps

Year constructed: Due to open 2016

Cost: £6.9b ($10.4b)

Temperatures above 1,000°C (1,832°F) cause reinforced concrete to collapse, but a special fire-resistant coating will withstand 1,400°C (2,552°F) for up to 90 minutes.



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Buildings with brains

"Halochromic paints change colour if the underlying metal begins to rust"

Concrete has been used since Ancient Roman times, but the modern version comes in a lot of exciting new flavours. Concrete can be made extra light, extra dense, springy, translucent and even self-healing, while glass can be shatterproof, load bearing and heatproof. And there are totally brand-new materials too...

Magnetorheological fluid normally behaves as a liquid, but in a magnetic field it stiffens to become solid. Pistons filled with this wonder fluid can act as dynamic shock absorbers with great strength and lightning-fast responses. Previously this was the preserve of high-tech vehicle suspensions, but engineers are now starting to use magnetorheological dampers to control earthquake vibrations in tall buildings.

Halochromic paints change colour if the underlying metal begins to rust. This tech is still being trialled for use on aircraft, but one day could warn if a bridge needs repainting.

Fire is a threat to all buildings but the danger is particularly acute in skyscrapers. However many storeys you stack on top of each other, everyone still has to evacuate via the ground floor. The Burj Khalifa has over 160 floors and so taking the stairs all the way down just isn't practical. Instead the elevators feature water-resistant equipment, redundant power supplies and drainage sills to keep water from the sprinklers out of the lift shafts. If you do need to take the stairs, there are pressurised, air-conditioned refuge areas every 25 floors to allow evacuees to rest and the stairwells are built from highly fire-resistant concrete.

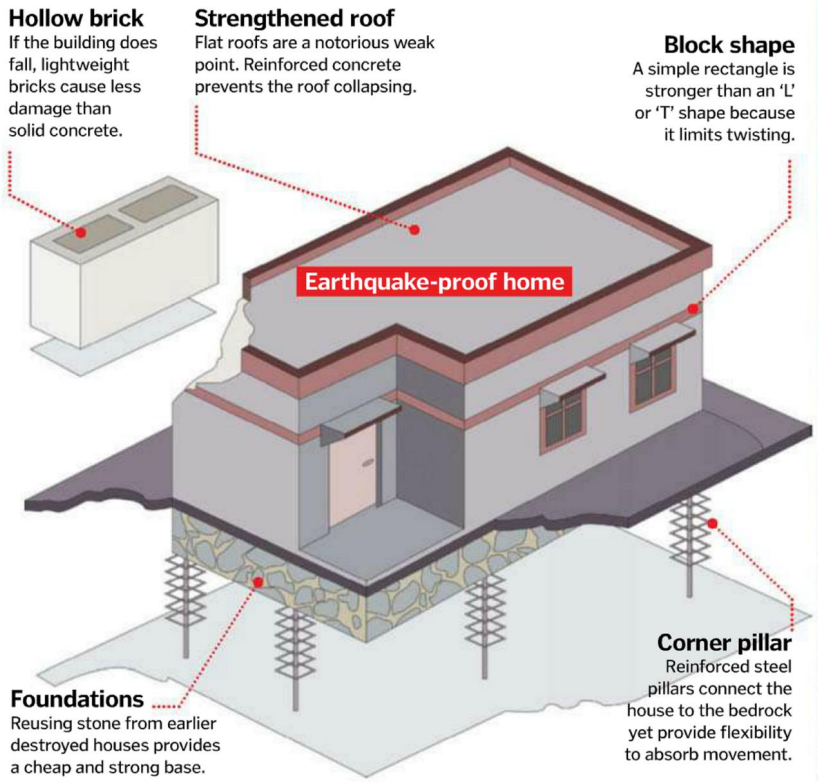
In 1956 the architect Frank Lloyd Wright proposed the Mile High Illinois Sky-City. A steel-framed building 1,600 metres (5,250 feet) tall would have swayed far too much using the construction techniques of the time, and the lift shafts would have taken up all the space on the upper floors, so the project was scrapped.

However, materials, techniques and technology have all come on leaps and bounds since then and a lot of the practical problems have now been solved. The Burj Khalifa is already more than half the height of Lloyd Wright's science-fiction design and human ingenuity shows no signs of slowing down.

Staying steady in an earthquake

Most office buildings and skyscrapers are built with floors and roofs resting atop wall pillars. Their strength comes from the huge weight pressing down. But this strength is a vulnerability in an earthquake as the floors collapse in on themselves. For medium-sized buildings, the best way to quake-proof them is to cut down on the weight. Lighter roofs and floors lower the peak stresses during an earthquake, while constructing concrete floors by pouring them in situ bonds them to the walls.

Some skyscrapers have huge roller bearings in the foundations that allow the whole building to slide without cracking. Tuned mass dampers can also be used to counter quakes.





£157bn

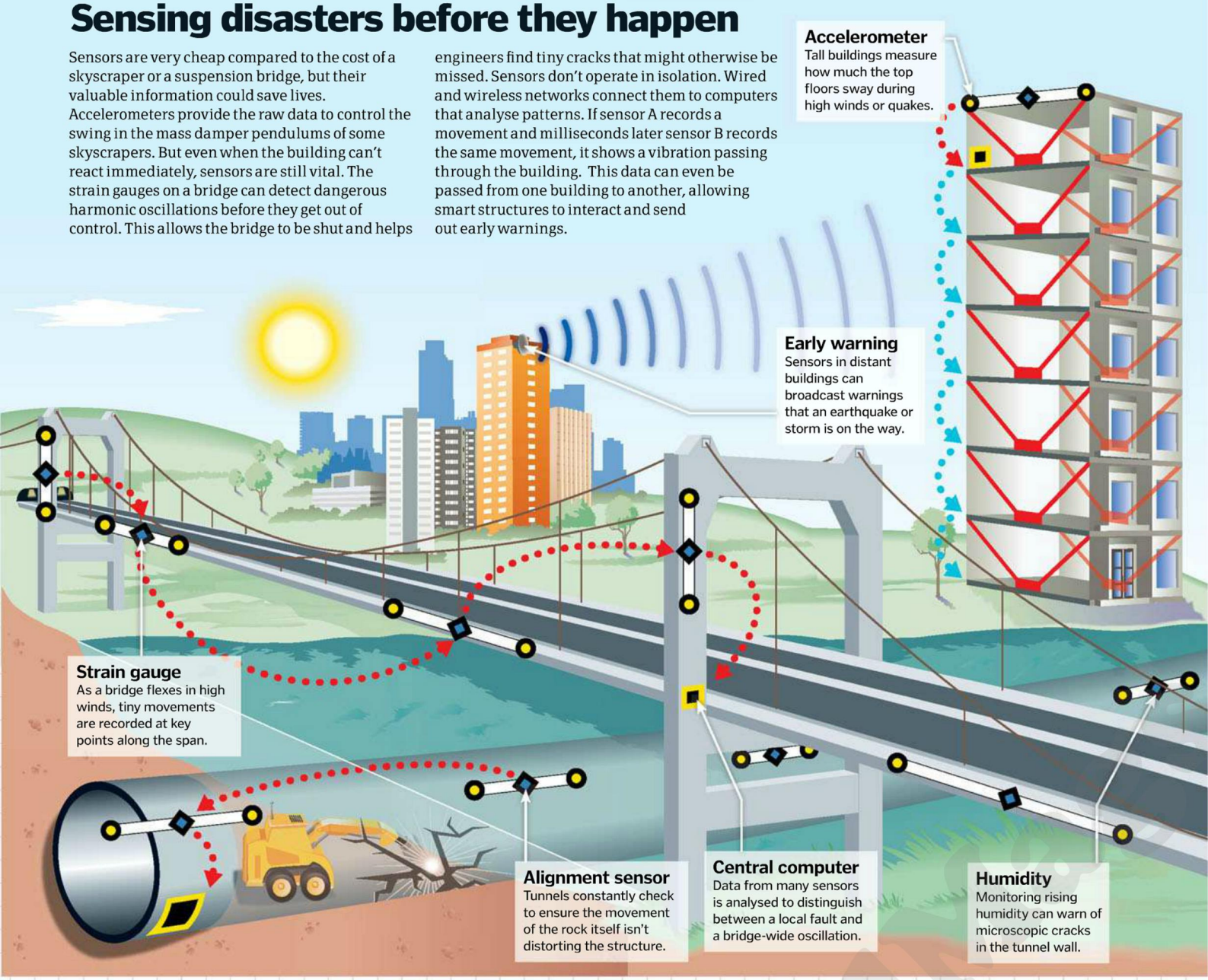
MOST EXPENSIVE EARTHQUAKE

The 2011 magnitude-9 earthquake and tsunami that struck Japan was the costliest natural disaster in recorded history. 129,225 buildings were completely destroyed and almost a million more were damaged.

DID YOU KNOW? *The emergency fire sprinkler system in the Burj Khalifa uses 213km (133mi) of piping!*

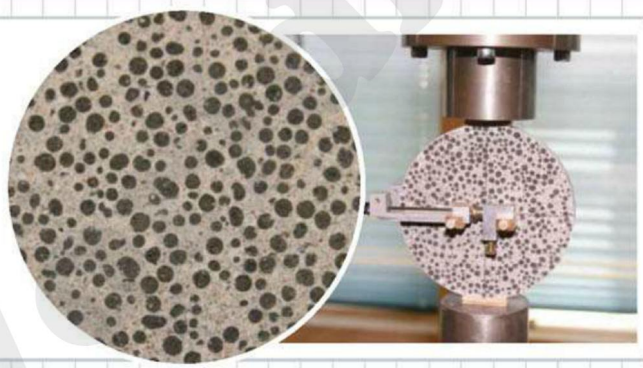
Sensing disasters before they happen

Sensors are very cheap compared to the cost of a skyscraper or a suspension bridge, but their valuable information could save lives. Accelerometers provide the raw data to control the swing in the mass damper pendulums of some skyscrapers. But even when the building can't react immediately, sensors are still vital. The strain gauges on a bridge can detect dangerous harmonic oscillations before they get out of control. This allows the bridge to be shut and helps engineers find tiny cracks that might otherwise be missed. Sensors don't operate in isolation. Wired and wireless networks connect them to computers that analyse patterns. If sensor A records a movement and milliseconds later sensor B records the same movement, it shows a vibration passing through the building. This data can even be passed from one building to another, allowing smart structures to interact and send out early warnings.



Concrete is getting clever

Building smart structures isn't just about attaching microcomputers; sometimes the technology is embedded in the actual building materials. Reinforced concrete is strengthened with steel bars, but steel isn't the only thing you can add to concrete. Adding plastic fibres with a special nonstick coating makes concrete as springy as wood. Alternatively adding optical glass fibres that run from one side to the other lets enough light through to make concrete translucent; that's not just attractive – translucent concrete can let you spot cracks deep within a block. But the ultimate building material doesn't just reveal cracks, it repairs them. A team in the Netherlands is developing concrete which has tiny capsules of special bacterial spores embedded in it (pictured). Any water that seeps in through hairline cracks reactivates the dormant spores. As they reanimate, they produce limestone as a by-product, which seals up the cracks.

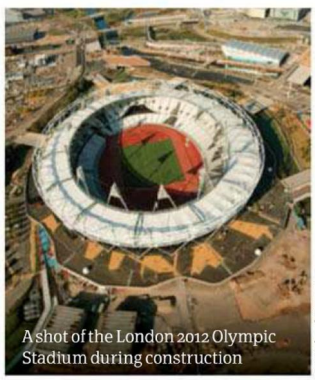


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"A good example of this fluidity is in its adoption of a completely removable second tier of seating"

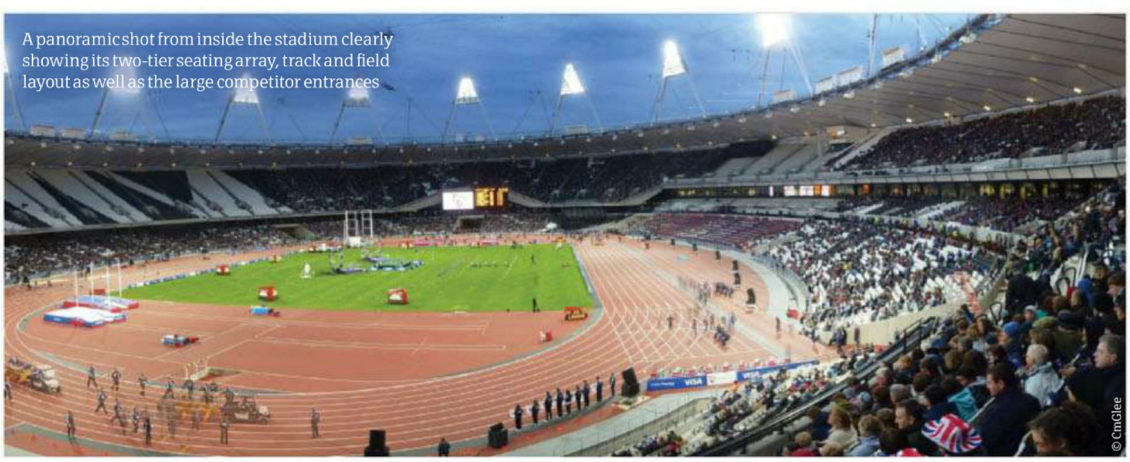
Inside London's Olympic Stadium

Discover how it was built, the materials that were used and which features make this the best-ever Olympic arena



A shot of the London 2012 Olympic Stadium during construction

© Michael Dunning



A panoramic shot from inside the stadium clearly showing its two-tier seating array, track and field layout as well as the large competitor entrances

© CmGlee

Let's kick off with some fast facts. The London Olympic Stadium was created by the excavation of 800,000 tons of soil – soil that was then reused in construction throughout the wider Olympic Park. The arena also took only 10,000 tons of steel to create, which is significantly less than any other Olympic arena built to date – indeed, the entirety of the impressive top ring of the stadium was forged out of pre-existing, surplus gas pipes.

The stadium's roof covers a huge 67 per cent of the seating within and was constructed out of phthalate-free polyvinyl chloride (PVC), which not only led to it being one of the most cost-effective stadium roofs in history but also one of the most environmentally sensitive. Despite these impressive construction techniques and materials, these are only a few of the reasons why the London 2012 Olympic Stadium is one of the best ever conceived.

A bigger, and arguably even more important, element of the arena is its construction to a super-flexible and fluid design brief, with the central venue split into three key sections: the track/field, lower-tier seating and upper-tier seating arrays. This clear segmentation of the huge, 80,000-seat stadium is due to an emphasis on sustaining its usability after the 2012 Games has finished, with key parts able to naturally evolve to suit a wide range of future events.

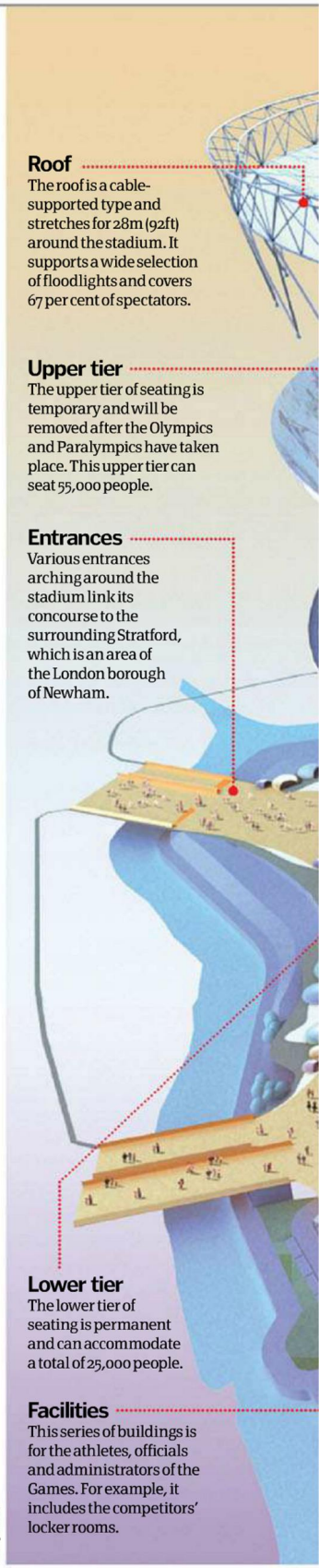
A good example of this fluidity is in its adoption of a completely removable second tier of seating, which despite providing a vantage point this summer for 55,000 spectators per event day, can be completely removed once the tournament is over, granting the local authority or private buyer a great deal of freedom in any re-specification. Indeed, it has been recently announced that the stadium will be adopted for the IAAF World Championships in 2017.

This forward thinking in terms of future evolution is also demonstrated in the design of the Olympic Stadium's concourse and convenience facilities, with the former granting a 360-degree freedom of movement for spectators and athletes around the vicinity of the arena, and the latter providing a host of facilities all positioned outside it; toilets, merchandise and catering booths, etc, are largely located in external pods.

All this sustainability and legacy, while impressive, has not however compromised the stadium's outfitting, with some cutting-edge technology and advanced facilities on display.

Within the stadium two custom-built Panasonic TV screens have been installed to show key events, scores and information to spectators – the screens each measure an insane 1,836 centimetres (723 inches).

In addition, a dedicated high-tech medical support suite has been integrated within the lower tier's infrastructure, enabling athletes to receive the best medical assistance on site. Also, athletes will have access to a dedicated 60-metre (197-foot) warm-up track and spectators will be able to access the stadium's concourse through five custom-designed bridges.



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DID YOU KNOW? *Work on the Olympic Stadium began in May 2008 and finished in March 2011*

The statistics...



© EG Focus/Bald Boris

London Olympic Stadium

Ground breaking: 2007
Opened: 2011
Location: Stratford
Surface: Track and field (grass)
Cost: £486m ($765m)
Capacity: 80,000

Curtain
A fabric curtain encircles the stadium's upper-mid structure providing shelter for spectators on the upper tier.

Track/field
At the centre of the stadium lies its track and field, on which the athletes will compete.

Concourse
At the ground level the concourse sweeps a full 360 degrees around the arena, providing visitors with plenty of room to find their entrance and relax between events.

Columns
The stadium is supported by a vast ring of concrete and steel columns, which are located within the inner concourse.

Pods
Surrounding the concourse is a series of pods; these supply a large portion of the stadium's catering and merchandise.

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"Cargo ship holds cut through several tiers of the vessel to create a massive, insulated storage bay"

On board a cargo ship

Capable of carrying thousands of tons of goods, these giants of the sea are as technically complex as they are enormous

There are several different kinds of cargo ship, each specialising in carrying various goods in tailored ways. But in general they can be identified by three key specific features, which we'll look at here.

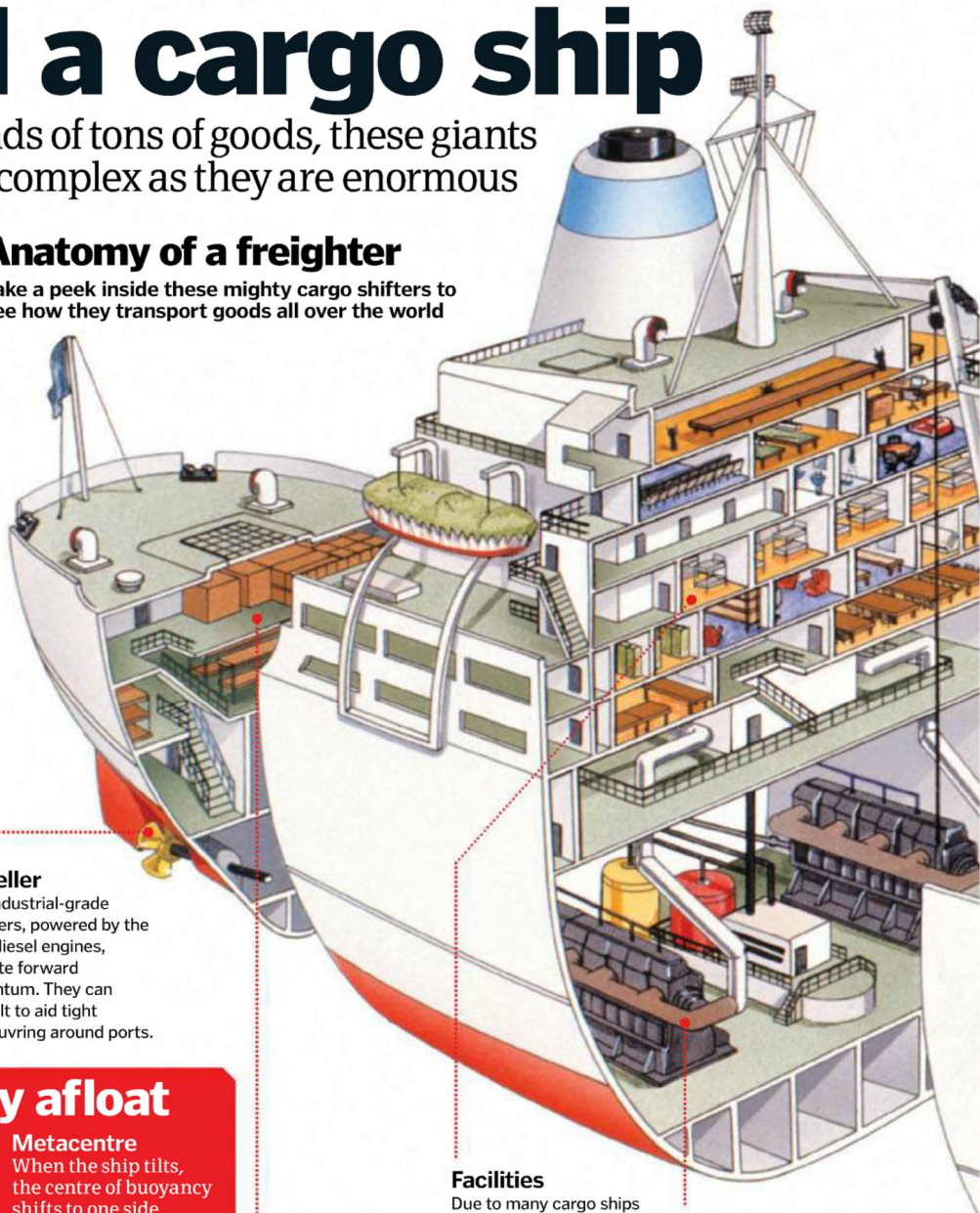
The first of these are deck cranes, static lifting platforms that specialise in distributing freight on and off the vessel, as well as into the ship's deep cargo hold. There are two main sorts: single, side-mounted deck arms – which often pivot on a hydraulically powered base, or inverted U-frames, where a grabbing arm moves horizontally between two fixed struts.

Another major feature, not surprisingly, is a large hold. These are typically located in the centre of the deck – though additional holds are sometimes included – and cut through several tiers of the vessel to create a massive, insulated storage bay. Containers are lowered into a hold via deck cranes or others situated on the port.

Lastly, cargo ships can be distinguished by their generally huge size – particularly notable in the height of their hulls when unladen. The latter design works to offset the extreme weight they carry when loaded, with a vast proportion of the hull submerged. This helps to maintain stability while manoeuvring under full load, the physics of which we look at in closer detail in the 'How cargo ships stay afloat' boxout below.

Anatomy of a freighter

Take a peek inside these mighty cargo shifters to see how they transport goods all over the world



Propeller
Vast, industrial-grade propellers, powered by the ship's diesel engines, generate forward momentum. They can often tilt to aid tight manoeuvring around ports.

Facilities
Due to many cargo ships travelling cross-continent to deliver their goods, a number of basic facilities are provided for the crew for rest and recreation.

Engine
Twin diesel-fuelled generators create a huge amount of horsepower to drive the ship's propulsion.

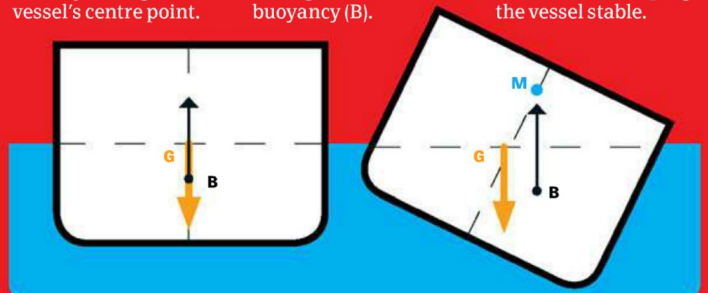
Auxiliary hold
Larger cargo ships may be equipped with more than one hold. These auxiliary storage areas are typically located at the front and/or back.

How cargo ships stay afloat

Mass
The weight of the ship's cargo acts upon it through the ship's centre of gravity (G). When level, this is directly through the vessel's centre point.

Buoyancy
The weight of the cargo is counteracted by the force of the water that's displaced by the ship's hull, which acts upward through the centre of buoyancy (B).

Metacentre
When the ship tilts, the centre of buoyancy shifts to one side, creating a metacentre (M) that compensates for the offset, keeping the vessel stable.



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13,500

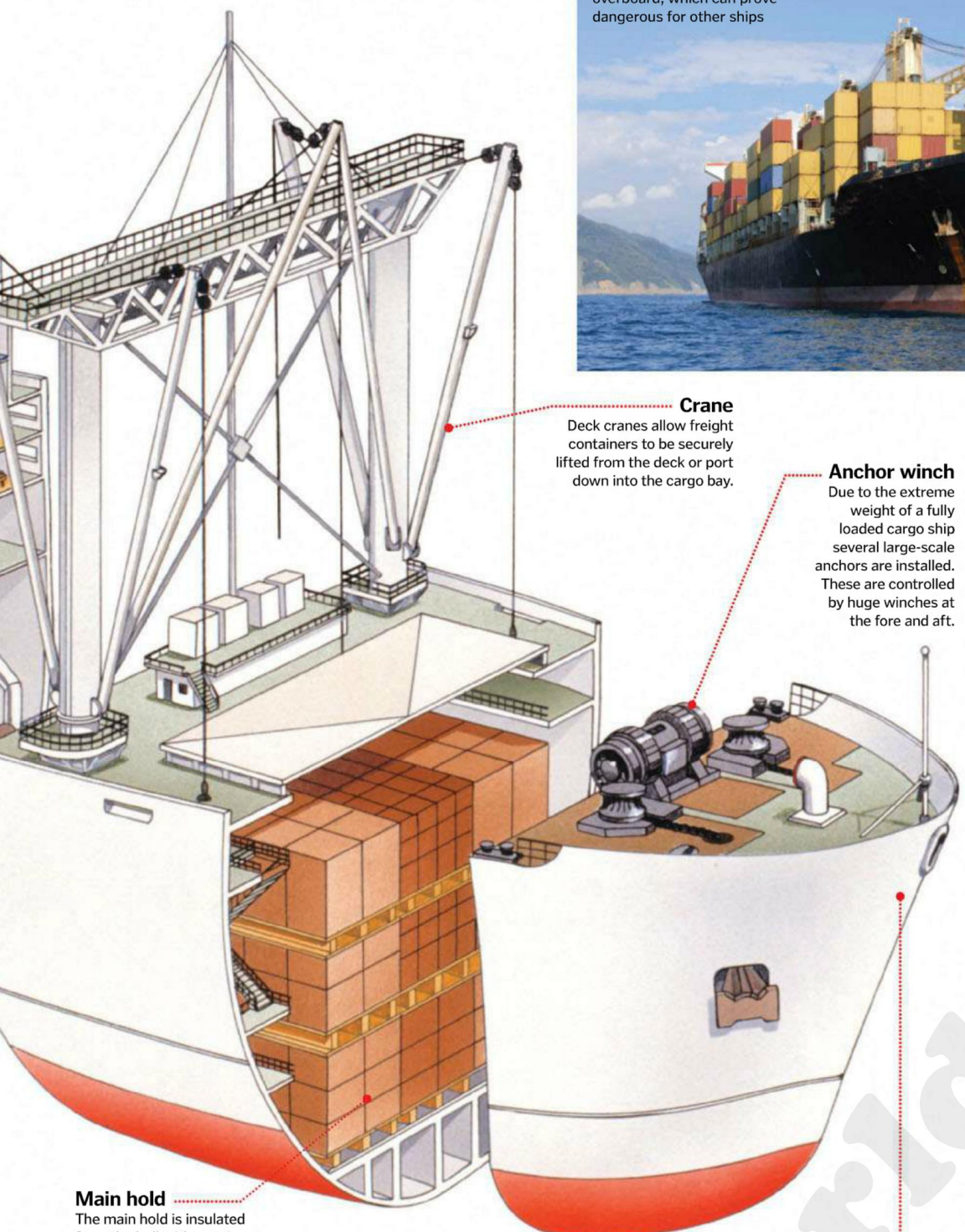
WORLD'S LARGEST CONTAINER SHIP

This is the number of freight containers that the planet's biggest container ship – the Edith Maersk – can carry at any one time. The Danish-built vessel measures 397 metres (1,302 feet) long.

DID YOU KNOW? *The longest ship ever built was the ULCC Seawise Giant supertanker, which measured 458.5m (1,504ft)!*



It's estimated up to 10,000 containers a year are lost overboard, which can prove dangerous for other ships



Crane
Deck cranes allow freight containers to be securely lifted from the deck or port down into the cargo bay.

Anchor winch
Due to the extreme weight of a fully loaded cargo ship several large-scale anchors are installed. These are controlled by huge winches at the fore and aft.

Main hold
The main hold is insulated from the hull with a series of protective enclosures. It is accessed through a top-mounted deck hatch.

Hull
A large, tall hull is structurally reinforced to protect internal cargo and keep the ship stable in rough seas while laden.

The cargo ship family

1 Cargo ship
A catchall term, cargo ships are typified by deep hulls and deck cranes.

2 Oil tanker
Oil tankers are notable for their lack of cargo hatches and minimal external handling gear. They consist of a series of internal, discrete tanks, a double hull and they feature very tall hulls.

3 Dry bulk carrier
Long and relatively flat vessels – like big barges – dry bulk carriers specialise in transporting coal, grain, ore and other loose, dry products.

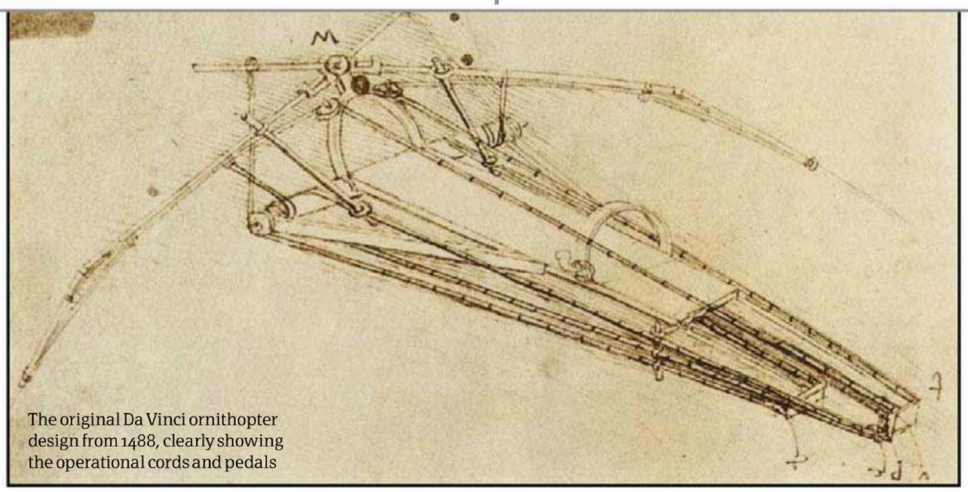
4 Container ship
The easiest carrier to recognise, container ships carry freight containers openly on their large decks. They may or may not have deck cranes, but will sit low in the water when fully laden.

5 Roll-on/off ship
This vessel specialises in carrying moving vehicles, with a hydraulically powered rear ramp leading to multiple tiers of parking. Like ferries they sit high in the water.

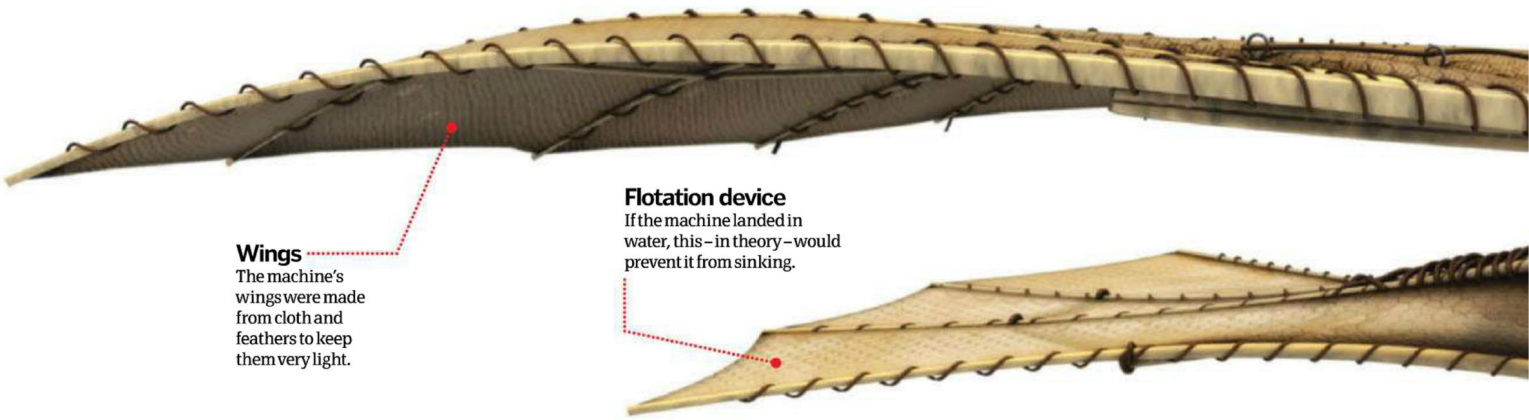
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"No one has attempted to fly an ornithopter, despite mechanisms being confirmed as fully functional"



The original Da Vinci ornithopter design from 1488, clearly showing the operational cords and pedals



Wings
The machine's wings were made from cloth and feathers to keep them very light.

Flotation device
If the machine landed in water, this – in theory – would prevent it from sinking.

Da Vinci's flying machine

Discover the operation of one of Da Vinci's most famous aviation designs, the ornithopter

This image is a 3D interpretation of Leonardo Da Vinci's flying machine, the ornithopter. Da Vinci designed the contraption in 1488 after studying the flight mechanics of birds. Indeed, in many regards the flying apparatus shares a lot of common features to the expert fliers, including a flexing, compound flapping motion as well as lightweight, feathered wings.

The flying machine operates as follows. A pilot lies down on top of the central wooden plank, hooking their neck and head through the semi-circle hoop and legs through the rear fastener. Once in position, the pilot can operate all parts of the machine with either their hands or feet. Foot operation entails pushing on two pedals situated at the rear of the aircraft – one opening the wings and the other closing them. The pilot's hands, meanwhile, can grip the frame and ensure smooth running of the cording, which is responsible for controlling the wings' multiple wooden struts.

Surprisingly, Da Vinci never built the machine for himself in the 15th century, nor did he proceed to test it – maybe due to the financial challenge such a project would entail, or the large potential for injury. In addition, while many enthusiasts have created direct replicas of the ornithopter from the original schematics, no one has attempted to fly them, despite the mechanisms having been confirmed as fully functional.

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5 TOP FACTS
FAILED FLIGHTS

Pigeon
1 According to Ancient Roman sources, the Greek mathematician Archytas invented a bird-shaped flying device which he nicknamed 'the pigeon'. It is alleged to have flown for 200m (656ft).

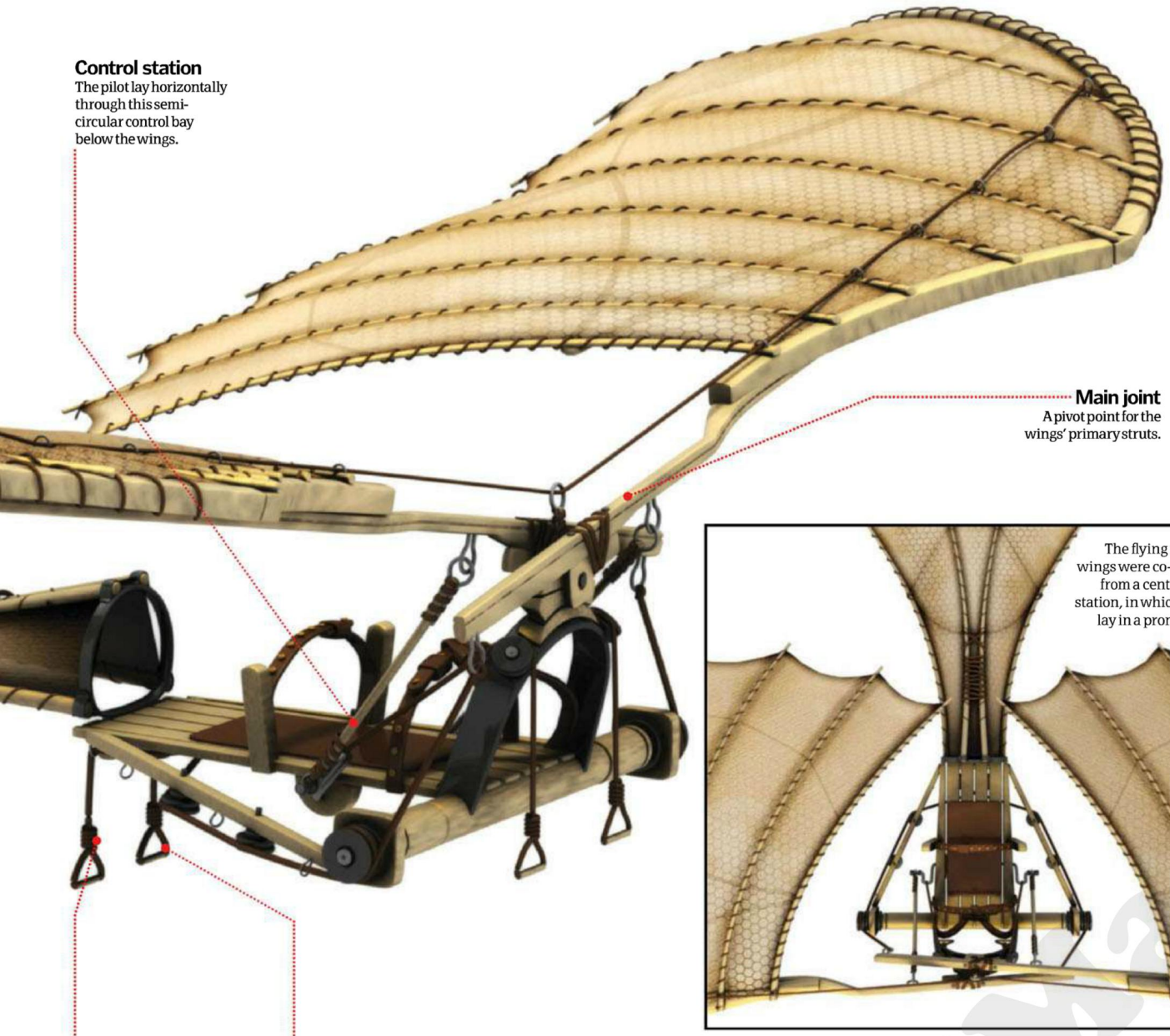
Vulture man
2 In the 9th century CE, Muslim inventor Abbas Ibn Firnas reportedly covered his body with vulture feathers and tried to fly. No account survives of his success, however.

The flying monk
3 In 1010 English monk Eilmer of Malmesbury is believed to have jumped off Malmesbury Abbey in a primitive gliding craft. Reports say he flew 180m (591ft) before crashing.

Airship
4 In 1709 Portuguese priest Bartolomeu de Gusmão demonstrated a small airship model before the Portuguese court, but he never succeeded in scaling the model up.

Tandem
5 In 1754 Mikhail Lomonosov showed a tandem rotor aircraft to the Russian Academy of Sciences. Similar to one of Da Vinci's designs, it was self-powered by a spring.

DID YOU KNOW? *In 1505, Da Vinci wrote Codex On The Flight Of Birds; this document would inspire many of his flying machines*



Control station
The pilot lay horizontally through this semi-circular control bay below the wings.

Main joint
A pivot point for the wings' primary struts.

Main pedal
The main pedal closed the wings in a six-step sweep. It was foot operated.

Release pedal
The release pedal opened the wings in a six-step sweep. Like the main pedal, it was controlled by one of the pilot's feet.

The flying machine's wings were co-ordinated from a central control station, in which the pilot lay in a prone position

"Surprisingly, Da Vinci never built the machine for himself in the 15th century, nor did he test it"

Who was Da Vinci?

An irrepressible inventor, Da Vinci created many machines and gadgets still in use today

Leonardo Da Vinci was an Italian Renaissance polymath (a learned person of many talents). He successfully conceived and built a wide number of tools, mechanisms and machines, many of which are still used in some form to this day. Examples include the machine gun, armoured car, bicycle, mechanical saw, dredger, file-cutter, excavating crane, mechanical drum and odometer.

In addition, he drew out numerous fantastical designs for more ambitious inventions that unfortunately never got adopted, one of which was the flying machine examined here. Other examples include a mechanical dragonfly, a self-propelled cart and a skull-shaped lyre. Da Vinci was born near Vinci, Italy, in 1452 and died near Amboise, France, in 1519, aged 67.



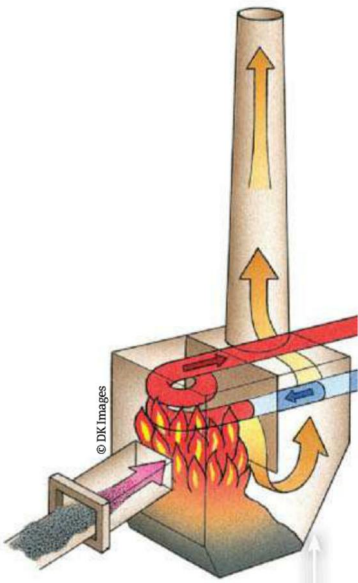
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"Due to the super-high pressure and speed, it produces a large amount of torque on the impeller's blades"



© Siemens Pressbild-Christian Kuhna

An enclosed steam turbine with a generator. The generator converts the turbine's rotational energy into electricity



© DK images

Modern steam turbines

1. Furnace
Heat for steam generation comes from the burning of fossil fuels (as shown here) or by nuclear power. Water is added to the furnace and converted into steam, before being funnelled to the turbine. The hotter the steam, the higher its pressure. Superheated steam is often used in steam turbines.

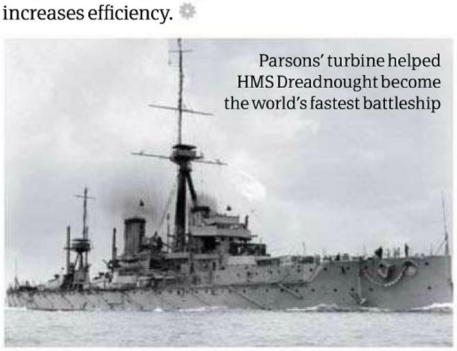
Responsible for up to 88 per cent of the Earth's generated electricity, steam turbines are an invaluable source of power

Steam turbines work by exploiting the high pressures attainable in superheated steam to generate mechanical energy, which in turn can be converted into electrical energy for use by society. In essence, all a steam turbine does is transfer the energy held by steam (at high pressures steam is incredibly dense and can release huge quantities of energy as it expands and cools) to a series of impellers, which spin at high speed. Consequently, when the rotor is inserted into an electromagnetic generator, it acts as the partner to the generator's stator, allowing electricity to be generated.

A single-flow steam turbine works as follows. First, steam is heated in a boiler, which is fuelled either by fossil fuels (coal/gas) or nuclear power, up to approximately 540°C (1,000°F). The steam is then fired into the turbine through a large valve at high speed, where it connects with the turbine's first bladed impeller. Due to the super-high pressure and speed of the steam, it produces a large amount of torque on the impeller's blades, causing the rotor to spin. The steam proceeds through a series of subsequent impellers, transferring its energy to them as it expands and cools, before being drawn out of the turbine at the far end to be condensed back into water. The water is then pumped back into the furnace to generate more steam.

Importantly, though, as the steam moves along the rotor, its loss of density means that the surface area of the impellers' blades needs to increase. In addition, due to the expansion of the steam, it increasingly needs to be directed at the optimal parts of the blades for maximum effect and to preserve thermal efficiency. This is achieved by positioning stationary bladed rings in between the moving impellers.

To elongate the period of time steam in a turbine remains dense and at high pressure, modern steam turbines are encased within a shell made from heavily alloyed steel. This, in partnership with the stationary bladed rings and angled impelled blades, preserves and balances the pressure drop along the turbine and increases efficiency.



Parsons' turbine helped HMS Dreadnought become the world's fastest battleship

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5 TOP FACTS
STEAM TURBINES

Tiny
1 Sir Charles Parsons' first steam turbine produced tiny amounts of electricity, with the model only producing 7.5kW. However, within ten years of that, models could generate 1,000kW.

Entropy
2 In an ideal steam turbine, the net amount of steam within it never changes. This perfect system does not exist, however, with efficiency ranging from 20-90 per cent.

Punching
3 Steam turbine speeds must be managed to prevent damage. Rotors must be carefully aligned, as any imbalance will cause severe vibration throughout the system.

Million
4 Steam turbines are now being built with a capacity of 1.3 million kW. These require alloyed steel blades and must be fed with steam heated as high as 34,500 kilopascals.

Heron
5 The invention of the first ever reaction steam turbine is credited to Heron of Alexandria, a Greek mathematician and engineer.

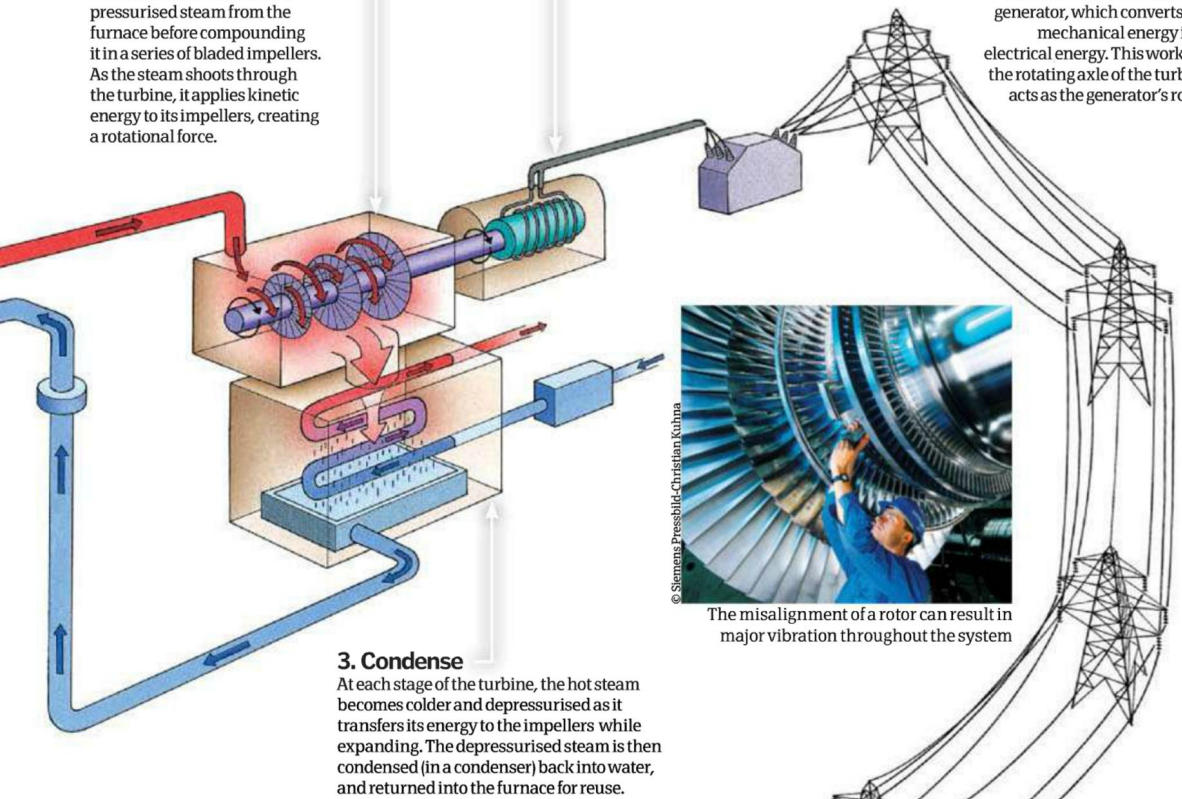
DID YOU KNOW? *The modern steam turbine was invented in 1884*

How steam turbines power your home

Follow our step-by-step guide to learn how a steam turbine coverts fossil fuels into usable electricity

2. Turbine
The heart of the operation, the steam turbine is fed hot, pressurised steam from the furnace before compounding it in a series of bladed impellers. As the steam shoots through the turbine, it applies kinetic energy to its impellers, creating a rotational force.

4. Generator
The rotational force created by the turbine is then fed into a generator, which converts the mechanical energy into electrical energy. This works as the rotating axle of the turbine acts as the generator's rotor.

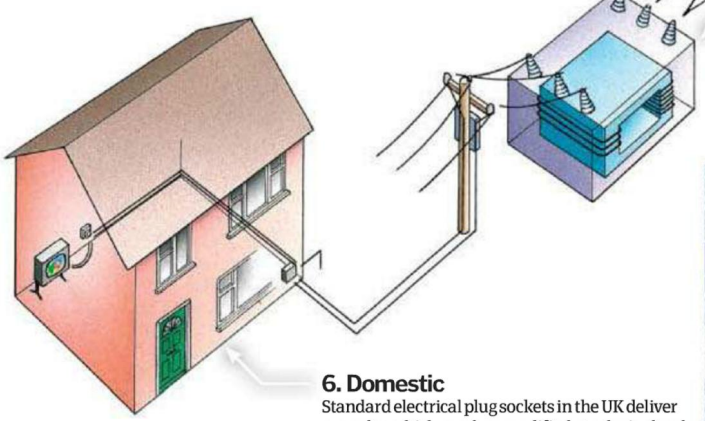


© Siemens Pressbild-Christian Kuhna

The misalignment of a rotor can result in major vibration throughout the system

3. Condense
At each stage of the turbine, the hot steam becomes colder and depressurised as it transfers its energy to the impellers while expanding. The depressurised steam is then condensed (in a condenser) back into water, and returned into the furnace for reuse.

5. Transformer
Because the electricity created by the power plant's generator usually has a high voltage when travelling the long distance to people's homes, a transformer is required to 'step it down' for commercial use. Both voltage and current can be stepped up or down as required, dependent on demand.



6. Domestic
Standard electrical plug sockets in the UK deliver 240 volts, which are then modified at a device level by auxiliary transformers in situ. This is a long way from the 7,200 volts carried by pylons. The transformer therefore 'steps down' the electricity allowing televisions, fridges and lights to operate.

Mounting a steam turbine is no easy task, with each weighing multiple tons



© Siemens Pressbild-Christian Kuhna



Meet the inventor

The modern steam turbine originates in the designs of English engineer Sir Charles Algernon Parsons. Parsons, a graduate from St John's College, Cambridge, radicalised established turbine designs – all of which subjected the mechanisms to huge centrifugal forces – by splitting up the changes in steam pressure into small fractional expansions over a large number of turbines in series. This allowed the velocity of input steam to be reduced significantly, and improved both efficiency and stability dramatically.

Parsons put his designs to use immediately and set up the CA Parsons & Company firm to produce his turbogenerators. Their success and, crucially, easiness to scale up in size, meant that before long they were installed in power plants all around the world. In addition to producing power for the public sphere, Parsons' turbines were also later installed into a number of European battleships to act as their main energy-producing engine. Most notable of these was HMS Dreadnought, which at the time (1906) was the fastest battleship on Earth thanks to Parsons' technology.

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"Only 40 or so years after Newcomen invented his engine, there were more than 100 systems in operation"

What was the Newcomen steam engine?

How did this groundbreaking engine work and how did it help bring about the Industrial Revolution?

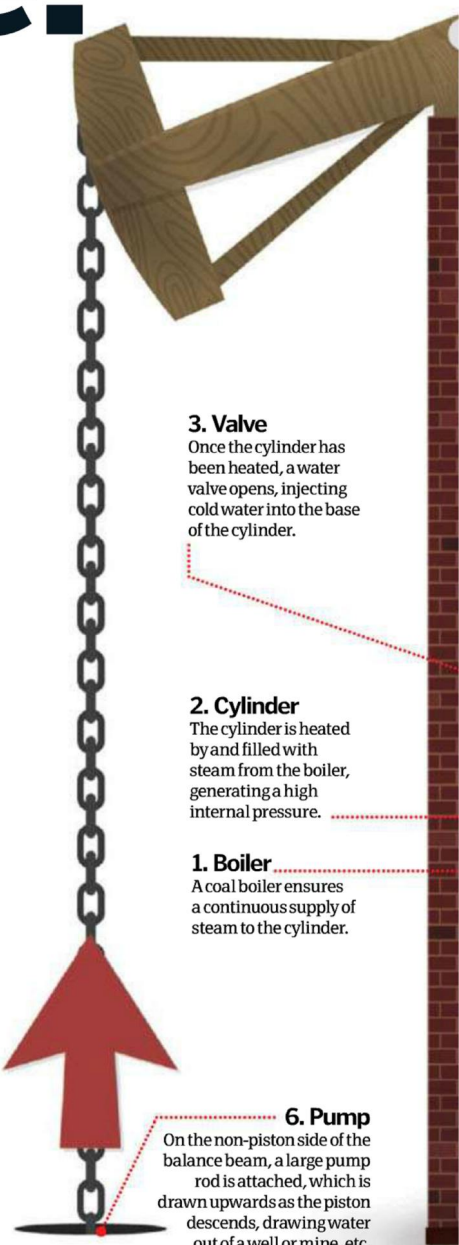
The Newcomen steam engine – which was named after its inventor Thomas Newcomen – was the world's first practical device designed to harness the power of steam for mechanical work. The first one was built in 1712.

The machine worked by combining the pre-existing technologies of a steam cylinder with a steam-driven piston to raise and lower a pump rod via a balance beam. For a complete mechanical breakdown of the process see the central diagram. The result of this combination enabled Newcomen to create a lifting engine that by simply burning coal could continuously pump large quantities of water out of wells, mines and other reservoirs without the need of manual labour (pumps were usually driven by horse prior to this invention).

Indeed, the relative simplicity of the device and cost-effectiveness when compared to maintaining a stable of animals, in combination with the rapid expansion of England's industry in the early-18th century, saw the machine surge in popularity, with Newcomen engines installed not just in England, Scotland and Wales but also mainland Europe. In fact, by the mid-18th century – only 40 or so years after Newcomen invented his engine – there were more than 100 systems in operation. For this reason, and in light of the massive role the steam engine would play in developing British industry, today Newcomen's game-changing invention is seen as one of the primary catalysts of the Industrial Revolution.

Not surprisingly, however, Newcomen's engine was incredibly crude by modern standards, and indeed those reached by the latter end of the 18th century. In fact it suffered from a fundamental flaw that was only addressed in 1769. This was that by directly cooling the engine's piston cylinder for each steam cycle, much of the boiler's generated steam was wasted bringing it back up to temperature in the next. This problem was exacerbated by the fact that the larger the Newcomen engine, the larger the cylinder and, as a direct consequence, the more steam was needed to reheat the cylinder. This led to ever-greater quantities of steam to be wasted in the heat-up process and so ever-more coal was burnt to facilitate this.

Regardless of this flaw, the Newcomen engine's ability to transform the power of steam into kinetic energy and mechanical work was a huge milestone in human engineering that played a key role in shaping British industry at this pivotal point in the country's history.



5. Beam
The downward movement of the piston pulls a balance beam down too, via a metal chain. The beam pivots on a central fulcrum.

3. Valve
Once the cylinder has been heated, a water valve opens, injecting cold water into the base of the cylinder.

2. Cylinder
The cylinder is heated by and filled with steam from the boiler, generating a high internal pressure.

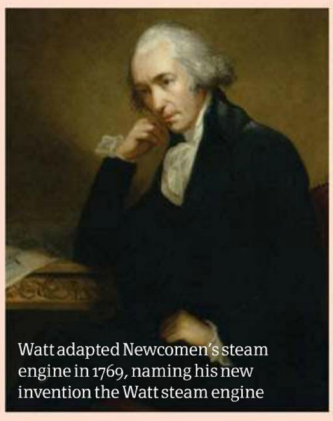
1. Boiler
A coal boiler ensures a continuous supply of steam to the cylinder.

6. Pump
On the non-piston side of the balance beam, a large pump rod is attached, which is drawn upwards as the piston descends, drawing water out of a well or mine, etc.

What did Watt do?

Today, James Watt is known as the father of the steam engine, but does he deserve all the credit?

As mentioned, the main problem with Newcomen's steam engine was that it was incredibly costly to operate. This was because each time its central cylinder was cooled to create a vacuum, the cylinder walls remained cold as the next wave of steam was fed in, condensing a proportion of it immediately. This reheating of the cylinder wasted a large quantity of steam, dramatically increasing coal consumption. This problem was solved in 1769 by Scottish engineer James Watt, who realised, while repairing an old Newcomen engine at Glasgow University, that if condensation took place in a separate container attached to the steam cylinder by pipe, the latter could remain hot at all times. Watt proceeded to patent his new steam engine and, despite it being heavily based on Thomas Newcomen's original, avoided paying any royalties by rigorously defending a number of lawsuits personally.



Watt adapted Newcomen's steam engine in 1769, naming his new invention the Watt steam engine

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5 TOP FACTS
THOMAS NEWCOMEN

Iron born
1 Thomas Newcomen was an ironmonger by trade and grew up in Devon, UK, a part of the country noted for its tin mines. He realised early on that flooding in the mines was a large problem.

Early prototype
2 In 1710 Newcomen combined a thermic siphon with a piston and cylinder to make his steam engine. By 1715, his engines were in use at the Conygree Coalworks and Wheal Vor mine.

Prolific
3 By the time Newcomen died in 1729, over 100 of his steam engines were in operation, throughout the UK. A few of his engines were even transported to continental Europe.

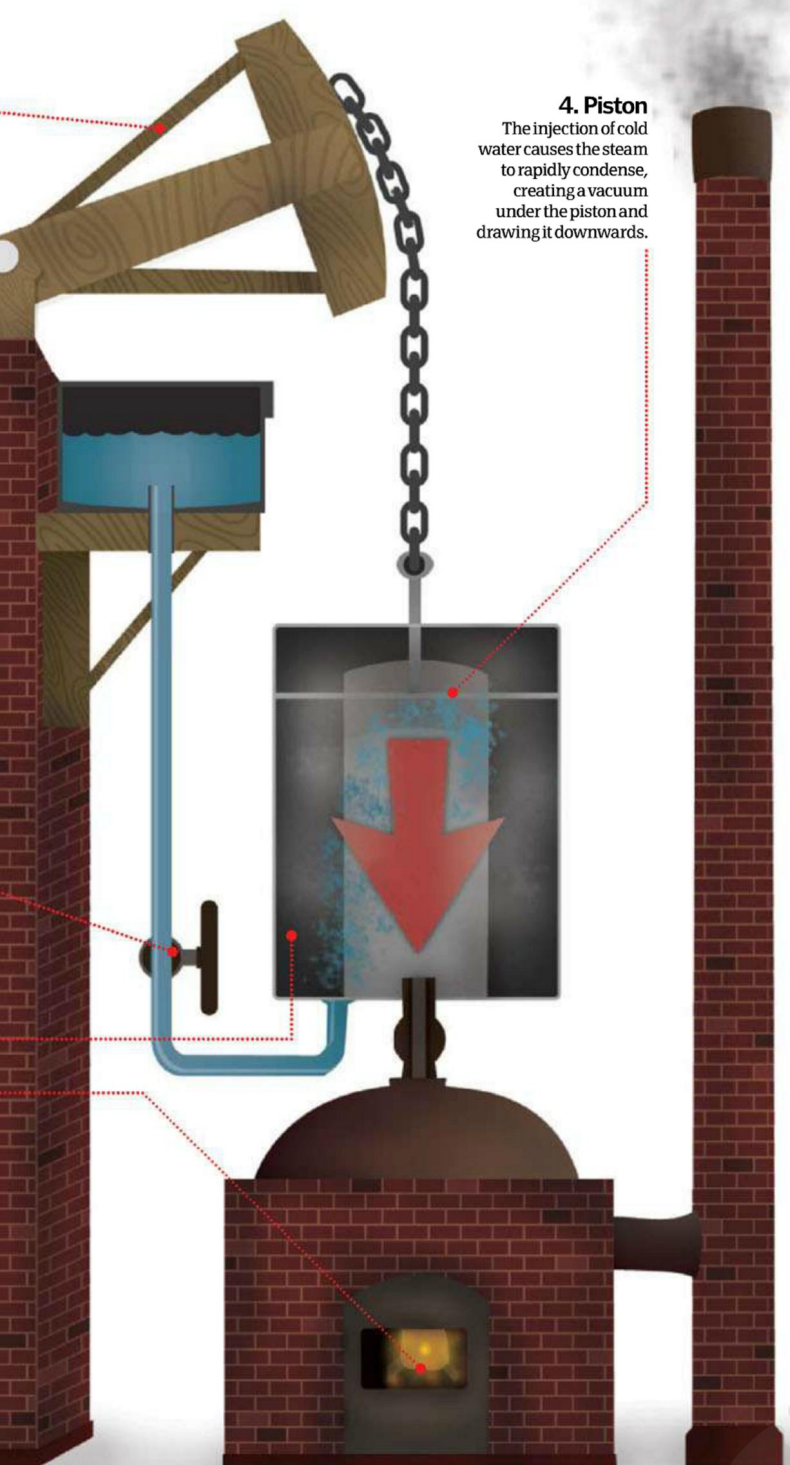
Totally Seine
4 In 1726 a Newcomen engine was installed at Passy, France, to pump water from the Seine River to Paris; it was the first to be used as part of a municipal water supply.

Survivors
5 Today there is only one working Newcomen engine left, a full-scale replica at the Black Country Living Museum in Dudley, UK. A few non-working models have also survived.

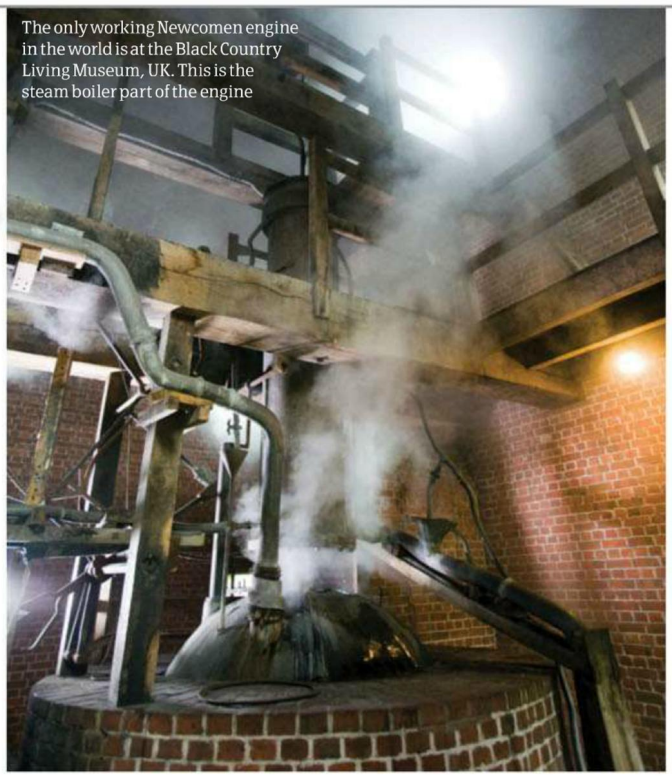
DID YOU KNOW? *The Newcomen steam engine was invented 300 years ago in 1712*

How did the Newcomen engine generate power?

Follow our step-by-step guide to the workings of this revolutionary piece of machinery



4. Piston
The injection of cold water causes the steam to rapidly condense, creating a vacuum under the piston and drawing it downwards.

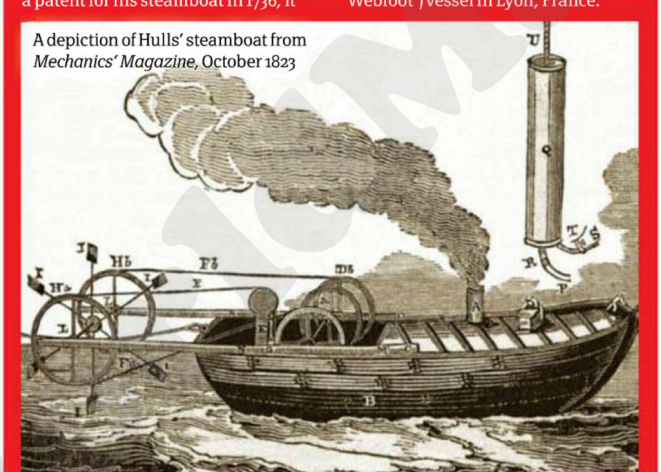


The only working Newcomen engine in the world is at the Black Country Living Museum, UK. This is the steam boiler part of the engine

Hulls' Newcomen steamboat

Although never made, this was one of the first attempts to create a steam-powered vessel

Since their inception, steam engines were increasingly seen as a future means of vehicle propulsion. A good example can be seen in English inventor Jonathan Hulls' design of a steamboat (below), a small vessel powered by a Newcomen engine. Unfortunately, despite being granted a patent for his steamboat in 1736, it was never built as the inefficient and cumbersome engine was thought infeasible. Interestingly, it wasn't until 1774 that a working steamboat was successfully piloted, with the Marquis d'Abbans, Claude-François-Dorothée de Jouffroy, both building and captaining the Palmipède (or 'Webfoot') vessel in Lyon, France.



A depiction of Hulls' steamboat from *Mechanics' Magazine*, October 1823

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A single power plant can power 180,000 homes

Electricity travels over 100,000 miles per second

AMAZING ENGINEERING!

ELECTRIC POWER

One of the cornerstones of modern society, electricity has been ever-present in our lives for over 100 years. While its production methods may have varied, its application and necessity ensure it will be ingrained in our lives for years to come. But what's next for electricity, how is it distributed, and how important is it really in our lives?

UK usage 2010: 44,000MW

Powerlines can carry 400,000 volts

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DID YOU KNOW?

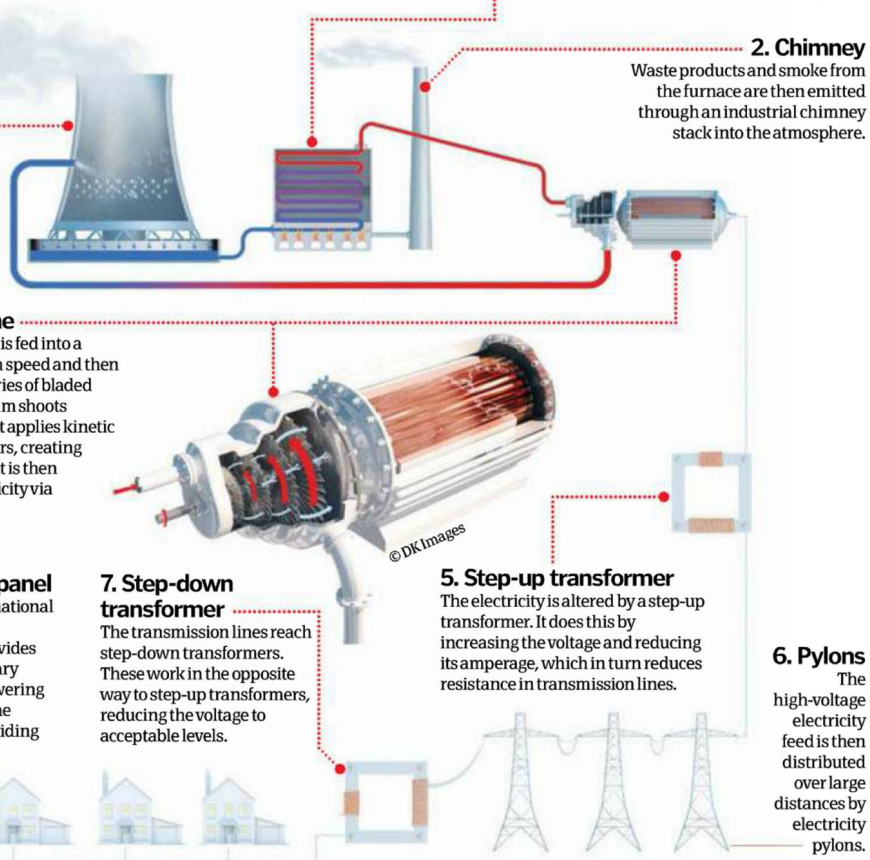
Why aren't plugs universal?

In the Sixties, when countries were beginning to set up their own power grids, each independently developed their own plugs to distribute power to homes and businesses. Today, each is heavily invested in their own design, so switching to a universal one would be impossible.

DID YOU KNOW? *The world's tallest electricity pylon hosting a single phase AC powerline is 111 metres high*

Electricity generation STEP-BY-STEP

From coal-powered plants to the personal PC, we explain the machinery and processes that deliver electricity to your home



Today, electrical power remains unrivalled in most of its applications. From kitchen appliances to televisions, electricity provides necessary energy throughout almost the entire world. However, the source of this electricity varies wildly from place to place, with some countries moving to greener technologies, and others remaining in the age of fossil fuels. For example, over 75 per cent of the electricity generated in France comes from nuclear power, with just five per cent from fossil fuels, but In the US almost 50 per cent of electricity comes from fossil fuels (mainly coal), with just over 20 per cent from nuclear power. But where does all this electricity actually come from? And what is really going on behind the scenes?

Electric power is distributed from power stations to your home through the power grid. In the UK this is known as the National Grid, while in the USA each state has its own power grid. Overhead lines have become such a part of our daily lives that we sometimes fail to notice them, but they're all around us and constantly supplying the electricity we need to power the world. All forms of electric power generation are fundamentally the same: some source of energy has to spin an electric generator. However, each method goes about doing this in different ways.

Electric generators convert mechanical energy into electrical energy. This is made possible by the relationship between magnetism and electricity, first noted by scientist Michael Faraday in 1831. A magnetic field will induce an electric current on an electrically conductive material, such as a wire, that passes through it. This is achieved by keeping the material or magnet stationary, and rotating the other around it on a turbine. As the magnet passes each section of wire, it induces a small electric current, and by continuing this across the entire wire, a large electric current is produced. Different electric power stations use different methods to cause this rotation, but the end result is always the production of electricity. The most common method of electric power generation is the steam turbine, found in fossil fuel power plants. By burning coal, oil or natural gas, steam is created that turns the generator to create electricity. Steam can also be ▶

Electrical definition glossary

Your guide to the language of electricity production, and how it's distributed to the home

ELECTRICITY
A form of energy associated with stationary or moving electric charges that provide power to devices that create light and heat. Electricity is the result of the accumulation or motion of electrons.

VOLTAGE
The force of an electric current as measured in volts – a unit of electrical potential, potential difference and electromotive force in the metre-kilogram-second system (International System of Units, SI).

WATTAGE
A unit of power in the International System of Units (SI) that is equal to one joule of work performed per second. Most electrical equipment is rated in watts, such as a 60-watt lightbulb.

CURRENT
The movement of any type of electric charge carriers, such as electrons, protons, ions or holes. When powering electrical devices through wire, the current is the quantity of charge passing any point per unit of time.

ALTERNATING CURRENT
A flow of electric charge that periodically reverses direction between two maximum values (the current's amplitude). In domestic electronics, low-frequency alternating currents are common.

DIRECT CURRENT
The opposite of alternating current. Direct current is a flow of electric charge that does not change direction. Direct current is produced by batteries, fuel cells and rectifiers.

TRANSFORMER
A device that moves electric energy from one alternating current circuit to others, while either increasing or decreasing its voltage. Transformers are often used to step down the voltage in a domestic circuit.

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"Alternating current is useful because it allows power to be sent across long distances"

How electricity gets home

produced in a nuclear power plant to produce the same effect. Alternatively, a hydroelectric dam can use water to turn a wheel, and ultimately power the rotating turbine of the electric generator.

Electricity that is sent to your home is in the form of alternating current (AC). Electricity that you'd get from a battery is known as direct current (DC). Alternating current is useful because it allows power to be sent across long distances. Buildings are supplied with electricity from power stations, and they convert this alternating current into usable power. Inside the plug of an appliance are three main components that allow this to be possible. The first is the live wire, which converts the alternating current of the grid into direct current to be used by appliances. The neutral wire carries out a similar role in addition to preventing surges of electricity by having the same electric potential as the earth, which stops the power supply rising uncontrollably in the case of a lightning storm or otherwise. The ground wire is always connected to the earth, and further protects against power surges and electric shocks. Inside a plug is a fuse that is designed to melt if the wires are overcome by a large increase in current, rendering the plug inactive and preventing the circuit being completed. Safety features like these have contributed to the widespread adoption of electric power as our main source of power over the past century, and it's more than likely that we'll be relying on electric power in the same manner for many more years to come.





Be careful where you fly your kites

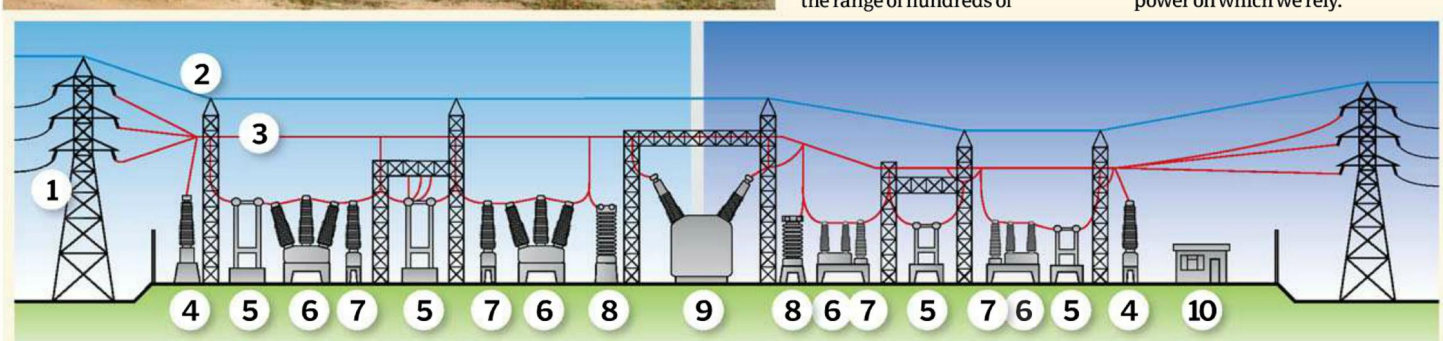
Substation breakdown

We highlight and explain the key components of these complex installations

Producing electric power in a power station is all well and good, but we need to be able to convert that power into a useful source. This is the role of electric substations, which make the high-voltage electric power usable.

Transmission voltages from power stations are very large, and can potentially be dangerous if allocated incorrectly. In fact, 'plugging' your house into a transmission voltage, usually in the range of hundreds of thousands of volts, would instantly blow all the electrical appliances, sockets and wires in your house. Substations lower this voltage to a distribution voltage, normally less than 10,000 volts, and allow our homes and buildings to receive useful electric power.

Below you'll see the stages of conversion at a substation, and how an array of wires, transformers and breakers are responsible for supplying the power on which we rely.



1. Primary power lines
The power lines deliver a high or low voltage electrical feed.

2. Secondary power lines
Whether the substation has stepped the feed's voltage up or down, the result is redistributed here.

3. Ground wire
Due to the large voltages and currents that regularly pass through the substation, it is grounded at multiple points for human safety.

4. Disconnect switch
An installation designed to disconnect the transmission lines or components to and from the system. If a transmission line develops a fault, then this can isolate it from the network.

5. Circuit breaker
Circuit breakers are used on larger substations in order to interrupt any short circuits or overload any currents that may occur on the network.

6. Current transformer
When a substation receives a current too high to measure, the current transformer reduces it, protecting the instruments and allowing an accurate reading.

7. Lightning arrester
This is a device that is used to protect the substation's insulation from the potentially damaging effects of a lightning strike.

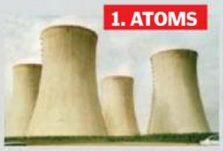
8. Primary transformer
This is the main device that is used to step up the feed's voltage and decrease its current or step down the voltage and increase the current.

9. Control room
The control room houses access terminals needed by the electricity grid's engineers to retrieve info from the substation.

10. Enclosure
Due to the high voltages at play in a substation, any metal fencing must be grounded for public safety.

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1. ATOMS

Nuclear

Water is heated by the process of nuclear fission in order to produce the steam required to rotate the turbine and generate electricity.



2. FIRE

Coal

The largest source of energy in the USA. Coal is burned in a large furnace in order to produce steam that rotates the generator's turbine.

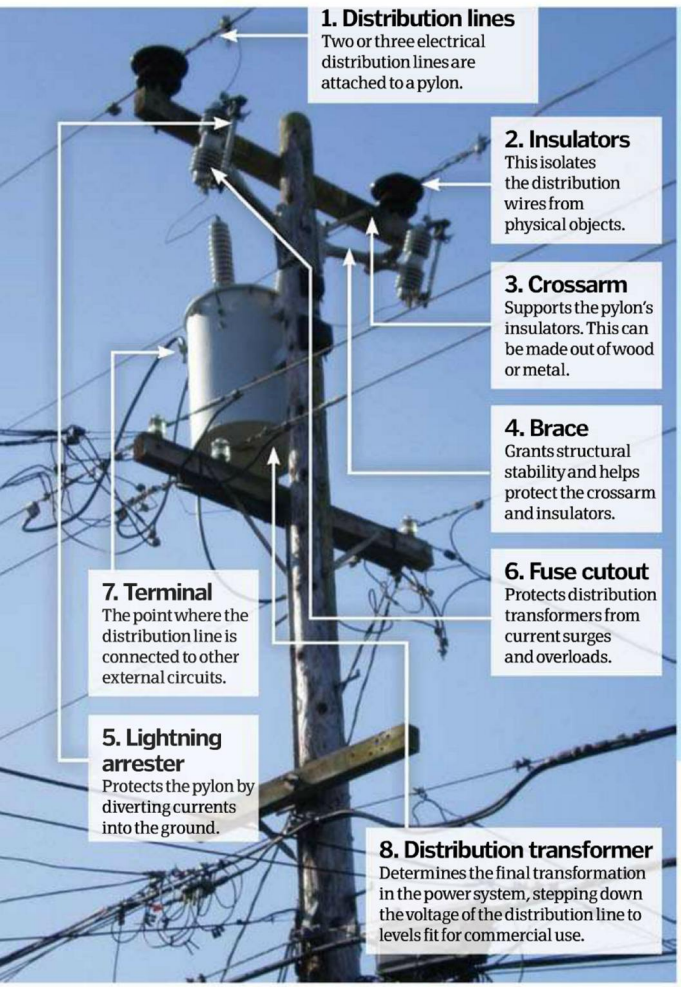


3. WATER

Hydroelectric

Water that is sourced either from a reservoir or a flowing river is diverted to rotate a wheel, which in turn rotates the turbine in order to produce electricity.

DID YOU KNOW? *There are a grand total of 88,000 electricity pylons in the United Kingdom.*



1. Distribution lines
Two or three electrical distribution lines are attached to a pylon.

2. Insulators
This isolates the distribution wires from physical objects.

3. Crossarm
Supports the pylon's insulators. This can be made out of wood or metal.

4. Brace
Grants structural stability and helps protect the crossarm and insulators.

6. Fuse cutout
Protects distribution transformers from current surges and overloads.

7. Terminal
The point where the distribution line is connected to other external circuits.

5. Lightning arrester
Protects the pylon by diverting currents into the ground.

8. Distribution transformer
Determines the final transformation in the power system, stepping down the voltage of the distribution line to levels fit for commercial use.

Anatomy of electricity pylons

Getting electricity from a power station to your home is a long and convoluted process. We see electrical pylons (known as transmission towers in the USA) almost daily, but they're such a regular part of our lives that we often fail to notice them, much less appreciate the job these structures perform. Pylons work in tandem across great distances in countries around the globe to provide the daily electricity responsible for large parts of modern life, often unknown to many despite their somewhat unsightly appearance.

Pylons are large structures that are constantly carrying high-voltage electricity. They are potentially very dangerous, and thus possess a number of safety features to protect against surges in current and overloads. They can range in height from just 15 metres (49 feet) to over 300 metres (980 feet), depending on their location and need. Check out our diagram to see just how these fascinating structures work.

Distribution panels explained

This panel forms the junction between your home's electricity circuits and the national electricity grid

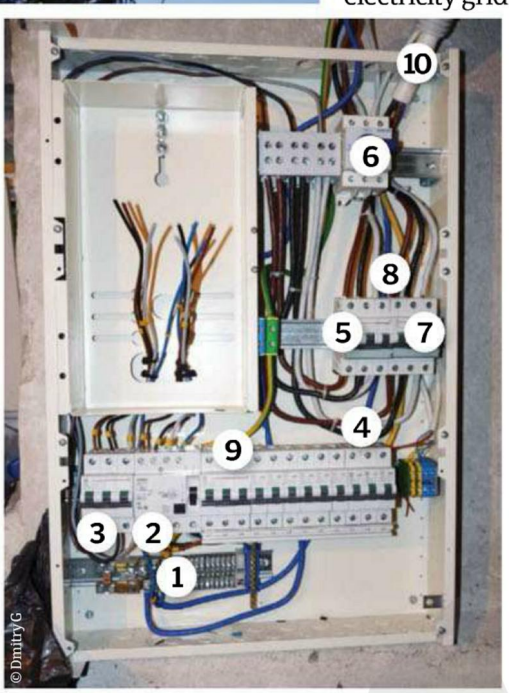
1. Ground connection/ ground wire
A metal conductor is attached to the ground wire in order to protect the panel in the event of a short circuit.

2. Terminal
This is part of the ground/neutral bus bar to which the unit's ground wire attaches.

3. Bus bar
This component receives the current from the neutral grounded wires of all circuits, and re-routes them to the neutral service wire and ground connection.

4. Neutral wire
A wire with no electric charge, the neutral wire allows currents to return to the distribution panel and the electricity grid.

5. Single/double circuit breakers
Two protection devices that in the event of an electrical surge or overload, cuts off the feed of both the 120-volt and 240-volt circuits.



© DmitryG

6. Main breaker
The main breaking unit of the entire panel, this can cease the supply of electricity to all the hot bus bars.

7. Hot bus bars
A conductive part of the panel into which the breakers for each circuit are plugged.

8. 120-volt circuit
The 120-volt circuit is formed from one live wire, one neutral wire and one ground wire. It feeds electricity to small appliances and lightbulbs.

9. 240-volt circuit
Consisting of twice the amount of wires than the 120-volt circuit, the 240-volt circuit feeds electricity to large appliances such as televisions.

10. Main power supply
The live distribution wire conducting the electric current into the panel enters through here.

MEGA STATS

Electricity is big business, and even bigger numbers. Here are a few stats that might just blow your fuse...

362,000,000,000
Kilowatt hours

The total amount of electrical energy produced in the UK from 2009 to 2010, of which 345 Bkwh were consumed. Generation comes from 80 per cent thermal sources, 13 per cent by nuclear plants, 6 per cent by renewables and 1 per cent by hydroelectricity installations.

47,000
Short tons

The quantity of coal the UK burned in electricity generation in 2010. This figure was significantly lower than 2006 – the highest point of a ten-year scale – where over 62,000 short tons of coal were burned.

86 GIGAWATTS (GW)

The total electricity generation capacity for the UK's privatised electricity sector. This is between four main distributors – EDF Energy, E.ON, RWE npower and Scottish and Southern Energy – over the national grid's transmission and transfer system.

22 MEGAWATTS

The total combined electrical energy capacity of Britain's ten nuclear power plants. Eight of these plants are operated by EDF Energy, and utilise advanced, gas-cooled and pressurised-water reactors. All of the gas-cooled reactors will be in service until 2023.

4 REACTORS

The proposed number of new pressurised reactors by electricity supplier EDF Energy to meet increasing energy demands over the next two decades. The new nuclear power plants would add 6,400 megawatts of generated electricity for consumption.

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"It is hoped that a new sustainable form of nuclear energy generation can be achieved"

What's inside a nuclear reactor?

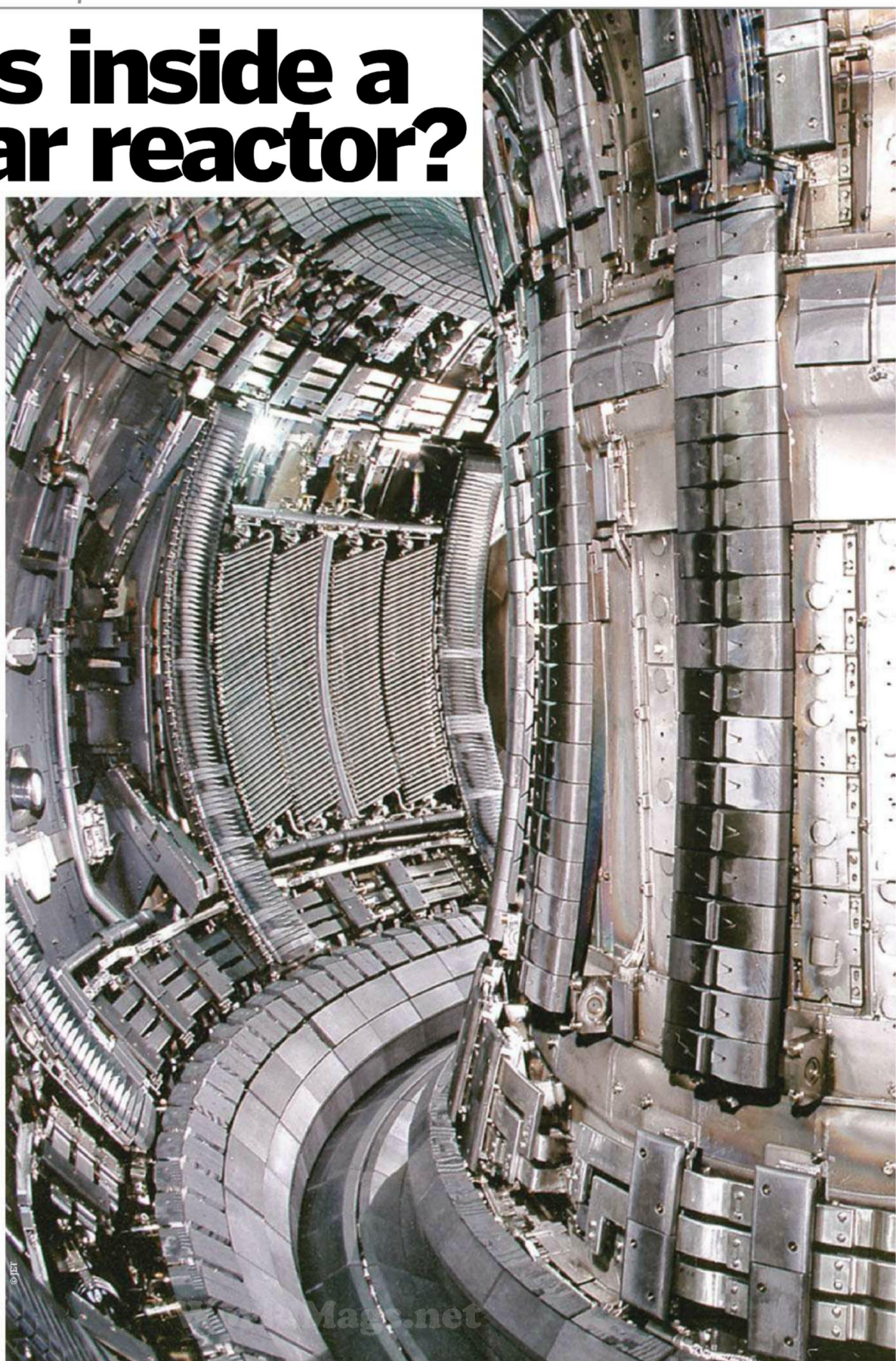
Welcome to the world's largest plasma generator

The Joint European Torus (JET) is the world's largest tokamak magnetic confinement, nuclear fusion device. The system, which is located in Oxfordshire, England, is an experimental system designed to generate nuclear reactions that are considerably more efficient and clean than those that are possible in current nuclear reactors.

The system works by generating super-heated plasma (100 million Kelvin) and containing it within a toroidal (doughnut-shaped) container vessel. The plasma is then trapped within the device through magnetic confinement, with the charged plasma particles forced to spiral along the circling magnetic field lines running around the vessel and not onto the walls of the system. This allows the plasma to be contained as it is heated up to the level needed for nuclear fusion.

The fuel for the fusion is a gas mixture of the two heavy forms of hydrogen, deuterium and tritium. These elements are chosen as they produce the most efficient fusion reactions on Earth. The gas mix is pumped into the JET and heated in order to turn it into the aforementioned plasma where conditions force the two elements to fuse, releasing a large quantity of energy.

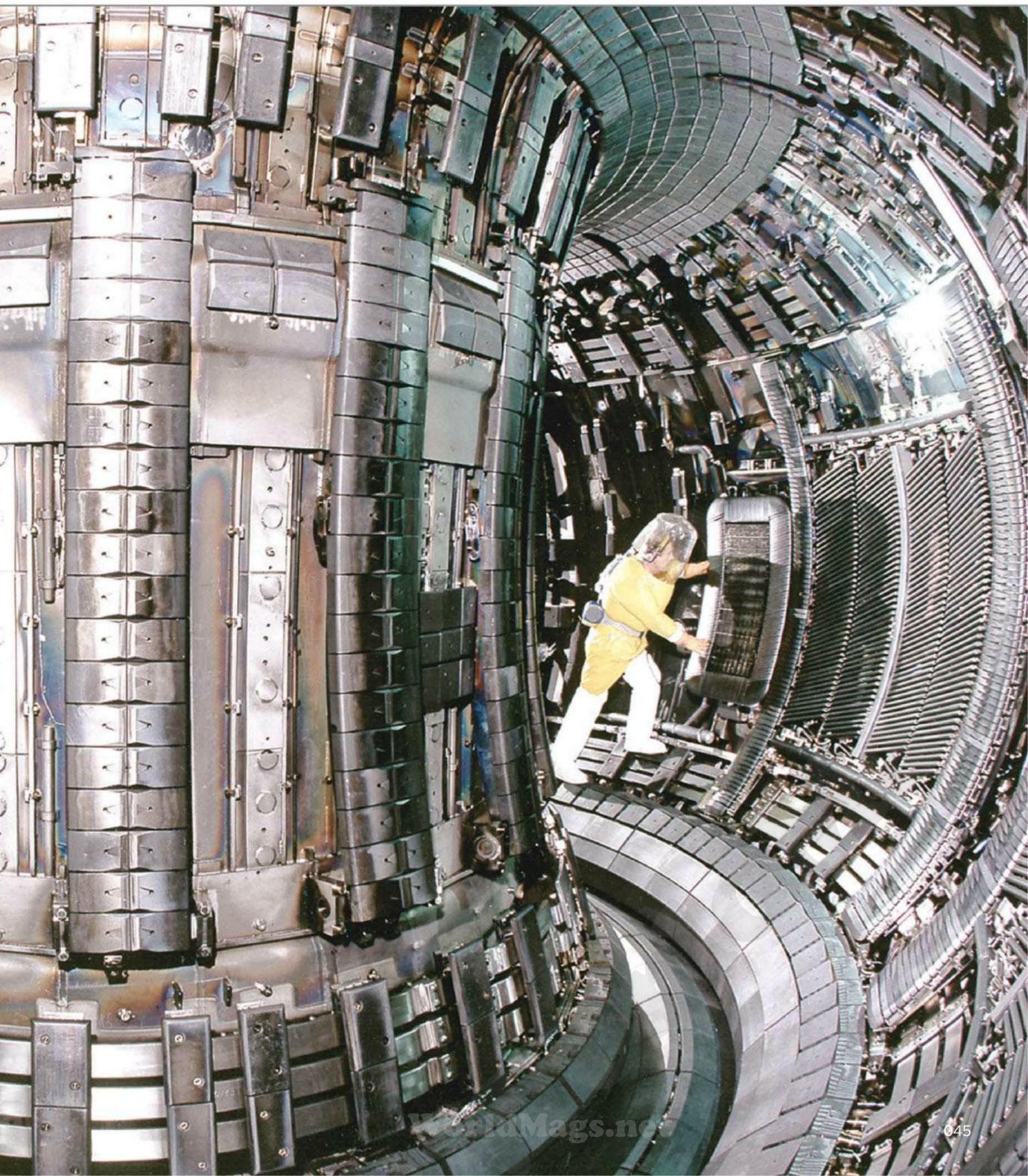
As of now, the JET system is being operated by a team of 350 international scientists to test the best methods of controlling the high-temperature plasma. Through this research, it is hoped that a new sustainable form of nuclear energy generation can be achieved to supply power for future generations, as well as reduce society's reliance on the rapidly diminishing fossil fuels.



What is it? – This image shows the JET, the world's largest nuclear-fusion, magnetic confinement system in the world. Systems such as JET confine plasma within a hollow, doughnut-shaped vessel, before heating it to levels high enough to instigate nuclear fusion in order to generate useable energy.

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DID YOU KNOW? *JET produces and contains plasma heated to 100 million Kelvin*



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"They're designed to provide safety from anything nature or man can throw at them"

Next-gen nuclear bunkers

Disaster shelters are still big business, but what's inside a modern nuclear bunker?

There are a number of reasons why a disaster shelter might be built. Along the east coast of the United States and parts of the Asian coastline, they protect people from hurricanes, flooding and typhoons.

In earthquake-prone regions, they shelter people from falling buildings and provide an escape route from surface rubble when all is clear. And typically across the Great Plains of the US, simple but sturdy shelters offer a safe subterranean retreat from tornadoes wreaking havoc on the surface.

Nuclear bunkers are the most robust of these shelters. They're designed to provide comprehensive safety from anything nature or man can throw at them, plus life support for many months – and even years for the most sophisticated examples. Smaller varieties tend to come pre-assembled, but larger and bespoke shelters are usually installed on site. The modern shape is a corrugated curve, made of fibreglass and composite, fire retardant and even bulletproof (for the entrance) materials. They're designed to avoid tensile loads, while seismic joints can withstand the kind of forces an 8.5-magnitude earthquake might yield.

Modern nuclear bunkers are sealed to prevent contamination from nuclear fallout and also to keep deadly radon gas and airborne toxins out, including weaponised viruses and bacteria. In addition, an 'overpressure choking system' with no moving parts prevents a nearby blast from causing excessive pressure inside the shelter.

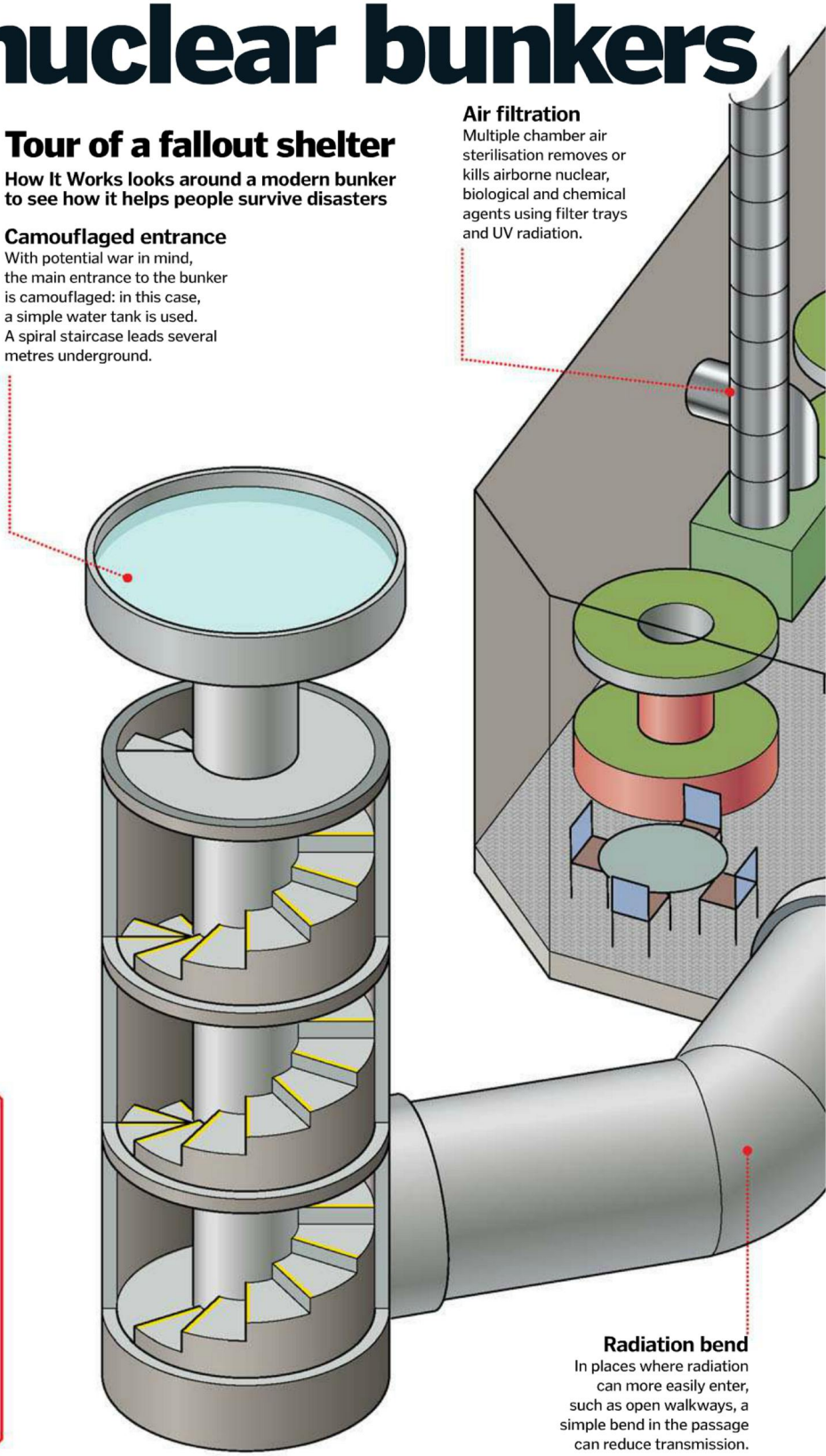
New nuclear bunkers are still a profitable business today despite the decades that have passed since the Cold War ended. While they are a fascinating feature for any household to have, we can only hope that no one ever has to use them for their intended purpose.

Tour of a fallout shelter

How It Works looks around a modern bunker to see how it helps people survive disasters

Camouflaged entrance
With potential war in mind, the main entrance to the bunker is camouflaged: in this case, a simple water tank is used. A spiral staircase leads several metres underground.

Air filtration
Multiple chamber air sterilisation removes or kills airborne nuclear, biological and chemical agents using filter trays and UV radiation.



Radiation bend
In places where radiation can more easily enter, such as open walkways, a simple bend in the passage can reduce transmission.

A sheltered life

Surviving the initial blast, the terrible heat and deadly radiation from a nuclear explosion is one thing, but the radioactive fallout alone can be enough to stop you from venturing outside for weeks. Basic accommodation in a good nuclear bunker will include a plumbing system with a ceramic water filter and high-pressure pump to keep drinking water clean and pass 'grey water' on for storage and potential recycling.

A longer-term bunker might include a hydroponics bay in which the grey water can be used to irrigate plants. Bunk beds come as standard and a well-stocked shelter will include dried, preserved goods, tinned food and other non-perishables that will last for an extended stay. Crucially important is some form of power generator as well as a battery backup, plus shielding for essential electronics like radios in the event of an electromagnetic pulse that can destroy sensitive equipment.

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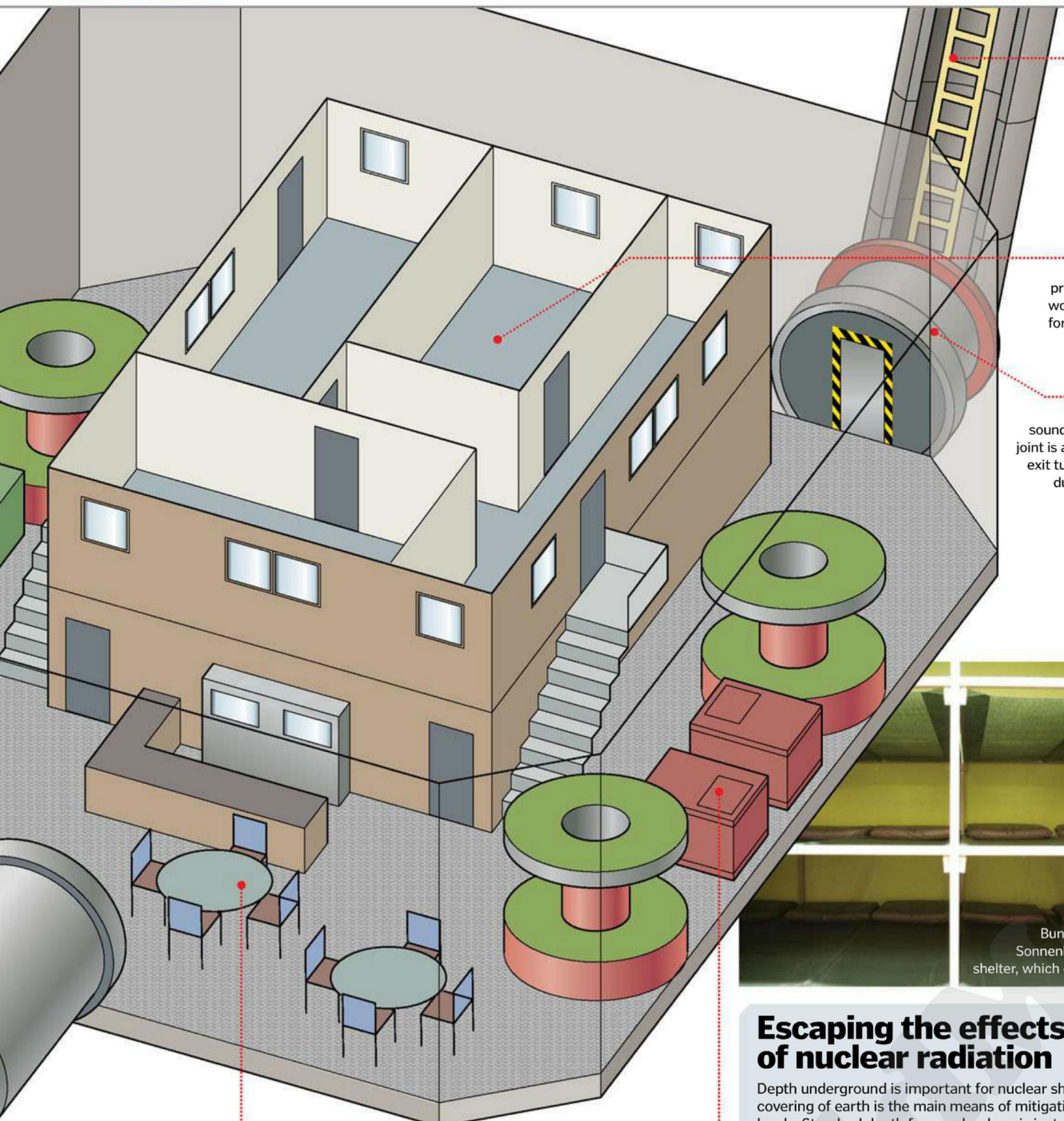
What else can a nuclear bunker be used for?

A A hotel B A library C A bank



Answer:
The Null Stern Hotel is a converted Swiss Cold War bunker in Sevelen, near Zurich. This Spartan accommodation – now a museum – was given a zero-star rating and cost £5.80 ($9.50) a night, though it was open 24 hours in case of emergency.

DID YOU KNOW? *In the Cold War, the US legislated fallout shelters that could withstand a 50-megaton blast for all new homes*



Escape hatch
In case the main entrance is blocked, an emergency hatch like this provides an alternative way out.

Sleeping area
Living space is at a premium, so bunk beds would probably be used for their small footprint.

Seismic joint
Both watertight and soundproofed, this seismic joint is a buffer protecting an exit tunnel from separation during a seismic event.

Bunk beds at Lucerne's Sonnenberg nuclear fallout shelter, which could sleep 20,000

Generator
Power is of course critical to survival, so low-noise diesel generators are backed up by pre-charged battery systems.

Dining area
This is a communal area where people would eat. The bunker would probably have its own hydroponics bay to grow fresh produce.

Escaping the effects of nuclear radiation

Depth underground is important for nuclear shelters as the covering of earth is the main means of mitigating radiation levels. Standard depth for new bunkers is just over 2.5 metres (8.5 feet), designed to reduce an overhead burst of deadly radiation from a one-megaton bomb to less than the effect of a single chest X-ray (0.01 sieverts) – which is harmless.

The sievert is used to measure the biological effects of radiation. From the gamma and neutron sources that characterise the deadliest parts of a nuclear blast's radiation burst, a person in good health can be exposed to a dose of up to 0.25 sieverts and suffer no ill-effects.

Curiously, a smaller 500-kiloton nuclear bomb exploding in the air can be more lethal than a much larger weapon on the ground. This is because nuclear air bursts produce much more deadly neutron radiation than surface bursts.

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"G-Cans was built to protect Tokyo City from flooding, which it is prone to during typhoon season"

The world's biggest drain

What does the planet's largest subterranean flood diversion facility do, where can it be found, and exactly why does it need to be so big?

Shutoken Gaikaku Housui Ro, otherwise known as G-Cans or the Metropolitan Area Outer Underground Discharge Tunnel, is essentially the world's largest drain. It can be found underground between the Showa region of Tokyo, Kasukabe in Saitama prefecture and the outskirts of Tokyo City. Loosely speaking it performs the same function as a standard drain – that hole in the road with a metal grille over the top that we encounter every day, which ultimately diverts excess surface water to avoid flooding. But it's on a totally different scale and much more sophisticated than that.

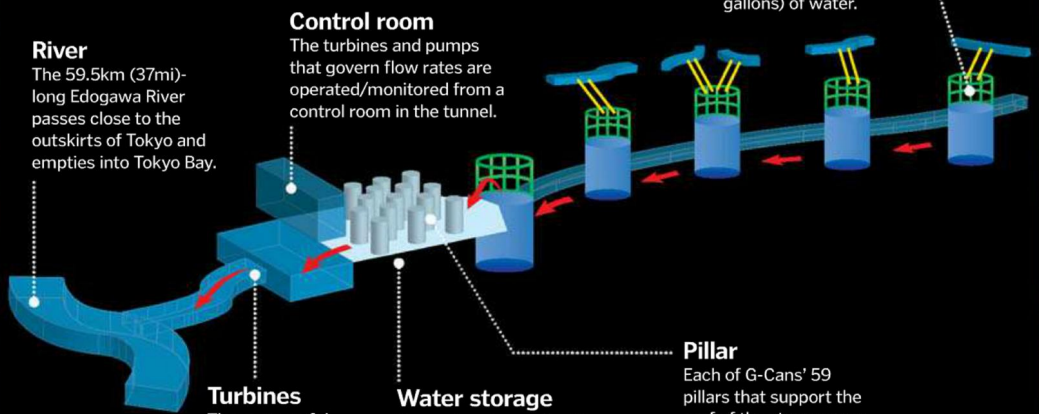
Five enormous silos, each 65 metres (213 feet) deep and 32 metres (105 feet) wide are spaced at regular intervals, within a certain distance from Tokyo's main rivers, including the Oochi Kotone, Kuramatsu, Arakawa and Nakagawa. They're connected by 6.5 kilometres (four miles) of tunnels 11 metres (35 feet) high and 50 metres (164 feet) under the ground that act as a flow regulator for floodwater. The real show-stopper though has to be the water storage tank into which this tunnel network empties.

The storage tank – which is also known as the 'Underground Temple' – is a marvel of engineering. 177 metres (580 feet) long and 25 metres (83 feet) tall, it's supported by 59 pillars and connected to 78 pumps. These in turn connect to ten-megawatt (14,000-horsepower) turbines that are monitored by a control room also located in the tunnel. These turbines enable G-Cans to pump tons of water out on a safer course farther upstream.

G-Cans was built to protect Tokyo City from flooding, which it is particularly prone to during typhoon season. This facility channels surface floodwater that can't be handled by the normal drainage system into the silos and then out to the Edogawa River on the outskirts of the city.

Where does all the water go?

Follow the path that floodwater takes under one of the world's busiest cities...



River
The 59.5km (37mi)-long Edogawa River passes close to the outskirts of Tokyo and empties into Tokyo Bay.

Control room
The turbines and pumps that govern flow rates are operated/monitored from a control room in the tunnel.

Silo
Each of the silos can hold over 5 million litres (1.3 million gallons) of water.

Pillar
Each of G-Cans' 59 pillars that support the roof of the storage area is 20m (65.6ft) tall and weighs 500 tons.

Turbines
These powerful turbines can pump up to 200 tons a second from the water storage out into the Edogawa River.

Water storage
The water storage facility itself is little more than an enormous chamber with the capacity to hold thousands of tons of water.

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17mn m³

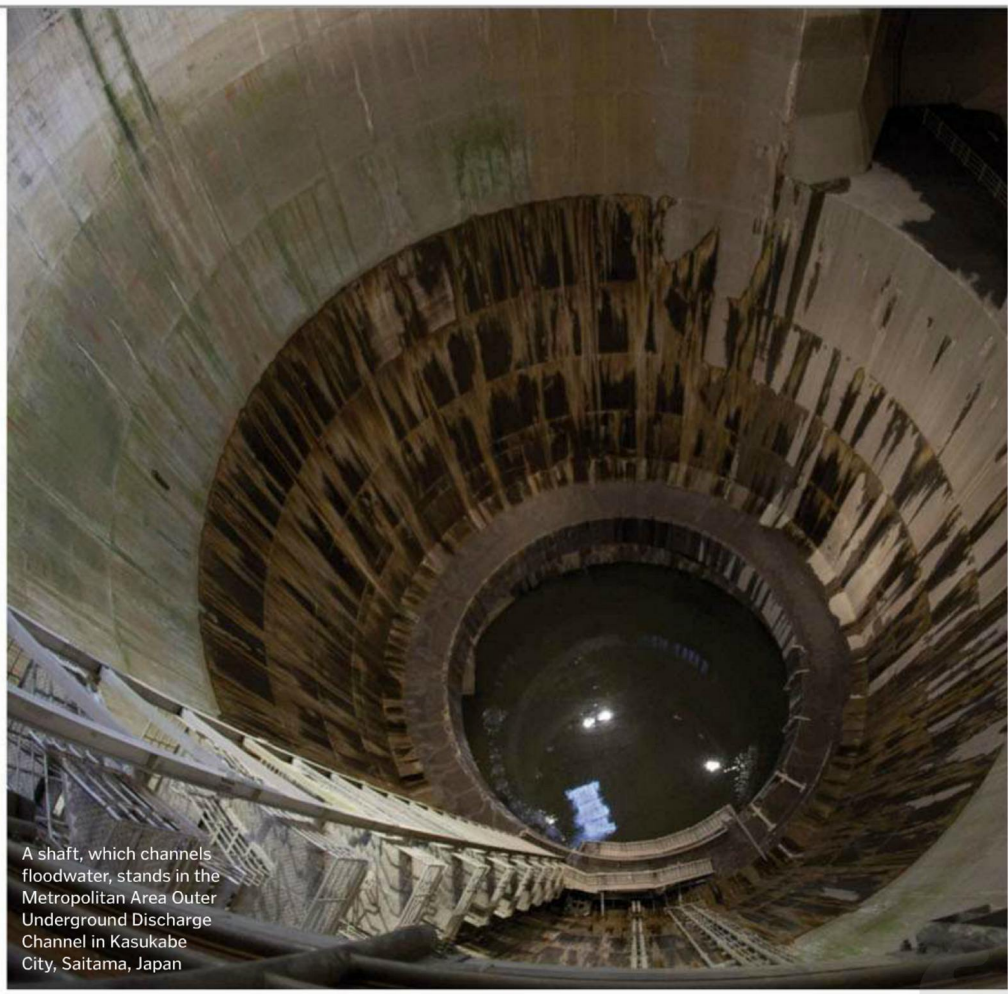
EARTH'S BIGGEST-EVER FLOOD

About 17 million cubic metres (600 million cubic feet) of water gushed out of an ice dam every second when a glacier burst by the Clark Fork River in the last ice age, sweeping over Oregon and Washington State.

DID YOU KNOW? *The water storage tank is often called the Underground Temple due to its cathedral-like appearance*

Boring the G-Cans tunnel

Tokyo has a history of major flooding dating back long before the city was even founded, but in the 20th century – with its population growing – monsoon rains and typhoons claimed the lives of thousands and destroyed millions of homes. So in 1992, work began on the G-Cans project to mitigate the effects of any such disaster. Due to the depth of G-Cans and the area's soft soil, engineers employed a tunnel-boring technique known as the shield method. The tunnel was bored using a huge metal cylinder (the shield), followed by a series of hydraulic jacks that push the machine forward and a system that erects concrete support segments. Because of the scale of the project, size of the tunnel and wet conditions, a slurry shield borer was also used, which uses chemical additives to soak up the moisture in the soil and stabilise the tunnel.



A shaft, which channels floodwater, stands in the Metropolitan Area Outer Underground Discharge Channel in Kasukabe City, Saitama, Japan

Tokyo floods

Located next to Tokyo Bay in the Kanto region of central Honshu – and with over 13 million inhabitants – Tokyo spans the alluvial floodplain of three major rivers in the area. The Edogawa and Arakawa Rivers meander around Tokyo's outskirts, while the Sumida River flows right through the centre. When the weather is relatively dry in springtime and late autumn/winter, living in one of the many regions of Tokyo that lie below the flood level isn't a problem. But the rainy season (or *tsuyu*) hits Japan in June and July, while typhoon season peaks in late-August through to October. A major part of Japan's annual average 1,800 millimetres (70.9 inches) of precipitation occurs during these months and devastating flash floods, as well as tidal surges brought on by terrible typhoon winds, can sometimes wreak havoc on communities – even with the additional flood protection afforded by G-Cans.

© Bloomberg via Getty

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"It has an undersea station capable of housing 24 divers and advanced logistical systems"

Mega pipes

The Nord Stream gas pipeline is an epic structure that offers a glimpse of the advanced engineering needed to fuel the modern world



Mukran facility
The Mukran facility receives raw materials for the pipeline by rail including cement, magnetite, sand and aggregate. These are shipped to the Swedish marshalling yards of Karlskrona and Slite for distribution.

Right now the planet's demand for energy is growing at an exponential rate. Each year more people are born and more homes are built to accommodate them, with each new property needing to be supplied with electricity and gas. This hunger for energy is ravenous and, looking forward, it seems to show no sign of abating.

To combat this ever-rising need for power, creative new energy-generating technologies are being implemented, with renewability at their heart. Progress has and is already being made in this pursuit, with wind farms, marine turbines and solar power stations increasingly contributing to national energy grids. This is undoubtedly the best way forward for our planet. Unfortunately though, right now the demand for energy far outweighs that being inputted by renewable sources, with a very real deficit needing to be addressed.

For Europe, that deficit is being met by the brand-new Nord Stream twin pipeline system, a 1,224-kilometre (760-mile) pair of gas pipes ▶



Lubmin plant
The German landfall facility lies in the Bay of Greifswald. This is a filtering station, with gas received via the Nord Stream cleaned and heated to prevent condensation prior to being distributed to people's homes.



The statistics...

Nord Stream

Length: 1,224km (760mi)
Pipe segments: 199,755
Diameter of pipe: 1.2m (3.9ft)
Pipe segment weight: 24 tons
Lifetime: 50+ years
Houses fuelled: 26mn

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5 TOP FACTS
NORD STREAM

Pitch perfect
1 The Solitaire pipe-laying vessel used to build the Russian end of the Nord Stream is nearly 400 metres (1,300 feet) long – the equivalent of four football pitches laid end-to-end.

Going with the flow
2 It takes 12 days for the gas to flow through Nord Stream's 1,224-kilometre (760-mile) pipeline running all the way from north-west Russia to north-east Germany.

Mega fleet
3 During Nord Stream's construction a total 148 vessels of various types were used. These were involved in survey, construction and logistics operations.

Weight for it
4 The total amount of steel used in the construction of the Nord Stream pipeline came to over 2.42 million tons – that's roughly 242 times the weight of the Eiffel Tower!

Equator
5 Prior to building, over 40,000 kilometres (24,850 miles) of marine terrain was geophysically surveyed – about the circumference of the Earth at the equator.

DID YOU KNOW? *The entire Nord Stream gas pipeline took just six years to build*

A tour of the Nord Stream

We look at the core facilities along the route of the pipeline and how the various stages were assembled

Operational zones
The Nord Stream is split into five overlapping operational zones, each with a dedicated marshalling yard and/or construction facility for efficient deliveries.



Marshalling yard
As well as the Kotka and Mukran facilities there are three other marshalling yards along the route, located at Karlskrona and Slite in Sweden, and Hanko in Finland. Pipes and materials are stored here for distribution by tankers.

Pipe anatomy

Within the corrosion-resistant layer lies the pipe's 27-41mm (1-1.6in)-thick steel cylinder.

Each pipe segment is surrounded by a 60-110mm (2.4-4.3in)-thick concrete coating.

Finally, on the inner face of the steel cylinder lies a 1mm (0.04in)-thick anti-friction layer.

Gryazovets-Vyborg pipeline
The Vyborg plant is fed with gas from the Russian gas network by the Gryazovets-Vyborg pipeline, a 917km (570mi) onshore supply line secured by six compressor stations. This pipe has a diameter of 142cm (56in).

Vyborg plant
The Russian landfall facility in Portovaya Bay near Vyborg receives gas from the Russian gas network and compresses it to adequate pressure for transportation via the Nord Stream to Germany.

Laybarge
Pipes from the carrier ships are installed by vast laybarges. These colossal vessels measure up to 397m (1,302ft) in length, needing to carry hundreds of pipes at any one time, as well as the range of machinery required to lay them.



Carrier vessel
Concrete pipes from the marshalling yards and Kotka and Mukran facilities are delivered to the Nord Stream's three laybarges on huge carrier vessels. These ships can transport hundreds of pipes on each journey.

The laybarge fleet



Castoro Dieci (165m/541ft)
The Castoro Dieci laid pipes in the German waters around the Lubmin region.



Castoro Sei (193m/633ft)
The Castoro Sei laid pipes in German, Danish, Swedish, Finnish and Russian waters.



Solitaire (397m/1,302ft)
The world's largest pipe-laying ship worked in Finnish and Russian waters.

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"As of January 2013, the pipeline has the capacity to transport up to 55bn m³ of natural gas per year"

▶ running along the bottom of the Baltic Sea. The pipeline links north-west Russia with north-east Germany and, as of January 2013, has the capacity to transport up to 55 billion cubic metres (1.9 trillion cubic feet) of natural gas per year from the gas fields of Siberia directly into the heart of Europe.

As you might expect, the pipeline is not without its critics. With a life span in excess of 50 years, the Nord Stream will see non-renewable energy continued to be spent and, due to the pipeline's large capacity, at an increased rate for the foreseeable future. In addition, due to the pipeline passing through 1,224 kilometres (760 miles) of the Baltic Sea, environmental organisations – including the World Wide Fund for Nature – have raised serious concerns regarding the project's potential to damage or displace complex ecosystems and delicate marine habitats.

While these environmental concerns are something we can't ignore in the long term, there is no denying the fact that the Nord Stream is one of the most impressive engineering feats ever undertaken. On both a macro and micro level, the project is centred around cutting-edge technology such as an undersea station capable of housing 24 divers, advanced logistical systems like pipe-laying barges up to four times the length of a football pitch, and supersmart electronics able to operate machines and vehicles hundreds of metres beneath the sea's surface.

In this feature we take a closer look at the Nord Stream twin pipeline system to find out not only how it was put together, but also – regardless of its non-renewable crutch – how it demonstrates just how science and technology can help improve the lives of millions and power future development.

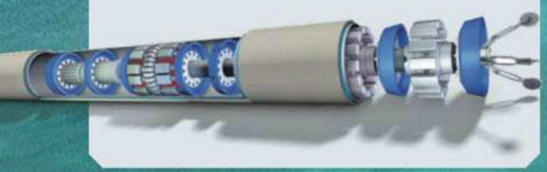


Diving system
The Skandi Arctic support vessel deploys an underwater station capable of housing 24 divers. The workers eat, sleep and live in the station for the duration of each installation.

Lift bags
Each pipe segment to be installed is equipped with lift bags filled with air. These bags can support up to 20 tons and help stabilise the pipe for manipulation by the PHFs.

The smartest PIGs on the planet?

The Nord Stream has its integrity checked regularly by pipeline inspection gauges (PIGs). PIGs are like intelligent drain cleaners, being inserted into the pipes before proceeding to automatically detect the smallest changes in the pipeline's structure – due to corrosion, for example – and recording that for later analysis at a control station. PIGs are also able to register any possible movements that the pipeline may have made since installation, such as those generated by small impacts. Each PIG is inserted into the Nord Stream pipeline via a launcher based in Russia, before being fired through the system and extracted in Germany. If any issues are detected, a maintenance and repair team is dispatched to investigate.



Pipe laying in action

Learn about the machines, tools, techniques and processes that go into laying undersea pipe networks

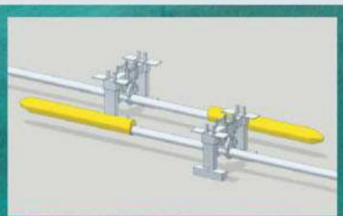
Pipe-handling frame (PHF)
The pipe-handling frames are responsible for positioning the pipes in the correct place for joining together. They can lift up to 150 tons and can move the pipes both vertically and horizontally.

Gravel bed
Prior to any pipe segments being delivered, a gravel layer is deposited onto the seabed. This provides a stable foundation for the welding habitat and pipe-handling frames during the installation.

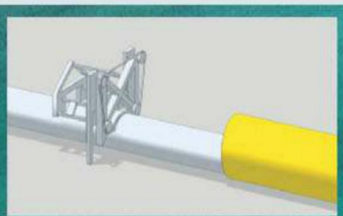
Emergency gas quad
If gas supply from the support vessel fails, an emergency supply can be gathered from the gas quad, providing the welding habitat with breathable air for up to 72 hours.

Tie-in sequence

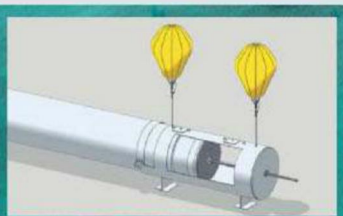
Follow the seven-stage process which was used to join two segments of pipe together



1. Survey
Prior to any human divers arriving at the installation site, a survey is conducted by ROVs to determine everything is in place.



2. Cutting
When in position, the pipe segments may overlap. If so, a diamond wire cutter is used to slice the high-tensile steel.



3. Plugs
Welding plugs are inserted into each end of the segments to hold back the water from the welding area of the habitat.

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KEY DATES IN THE PIPELINE...

2006
In November the logistics concept is started for the Nord Stream pipeline.

2007
A year later construction work begins on the Mukran site in Lubmin, Germany (right).



2008
June 2008 sees the first batch of pipes delivered to the Kotka distribution centre in Finland (right).



2010
Pipes begin to be delivered to the Nord Stream's three laybarges and, soon after, pipe laying commences.

2011
The gas for line 1 of the pipeline is switched on in November. Line 2 goes active a year later.

DID YOU KNOW? *The total construction cost of the Nord Stream was £6.4b ($10.1b)*





Diving bell
A transportation unit for the dive team, the diving bell can carry three people from the diving station to the subsea installation area. It has oxygen tanks that allow the divers to work in eight-hour shifts.

Remotely operated vehicle (ROV)
A selection of ROVs are controlled from the support vessel. Armed with sensors, instruments and cameras, the ROVs allow the installation area to be analysed from the surface.

Umbilical cable
The energy conduit for all of the Nord Stream's subsea installation equipment, this cable carries power from the support vessel as well as video feeds back to the surface for real-time inspection.

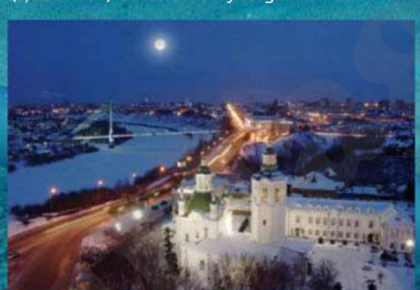
Environmental concerns

Laying millions of tons of concrete and steel on the Baltic Sea's seabed was not only an epic logistical challenge but also an environmental one. The potential effect to irreversibly damage the seafloor during the laying of a pipeline on this scale can be massive, displacing ecologies of ocean wildlife, injecting huge quantities of silt into the water and destabilising the landscape.

As such, prior to the laying of the pipeline more than 40,000 kilometres (24,850 miles) of geophysical surveys were conducted, with thousands of regions inspected and catalogued. This allowed the optimal route to be established in order to mitigate damage. In addition, to safeguard the sea since the installation, an environmental monitoring programme has been initiated that, with a fleet of specialist vessels including remotely operated vehicles (ROVs), will assess the water quality, seabed recovery and local fish, bird and mammal populations.

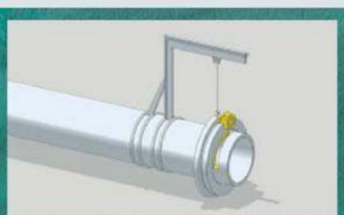
Siberian supply

The gas for the Nord Stream pipeline comes from the Yuzhno-Russkoye oil field in Tyumen Oblast, Russia. The pool of gas lies about a kilometre (0.6 miles) below the region's surface where there is estimated to be in excess of 1 trillion cubic metres (35 trillion cubic feet) of natural gas, with an additional 5.7 million tons of proven oil reserves. Currently there are 26 gas wells in operation at Yuzhno-Russkoye, extracting more than 15 million cubic metres (530 million cubic feet) of natural gas per day, the majority now flowing the 2,415-kilometre (1,500-mile) distance to Vyborg.

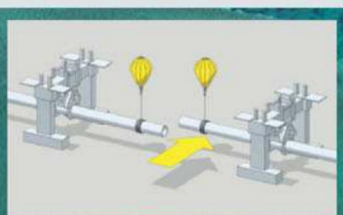


Welding habitat
A dry dock for the dive team as well as an industrial-scale welding machine, the welding habitat is responsible for joining segments of pipe. It is set up in-situ but controlled and powered from the support vessel.





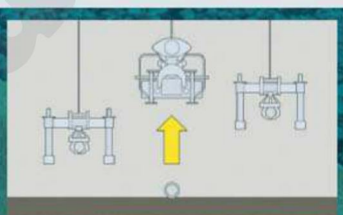
4. Bevelling
A bevelling machine gives both pipe ends a smooth finish. Their surfaces are measured to ensure they are uniform.



5. Lift
Three pipe-handling frames (PHFs) are used to lift and shift the pipe segments into position – vertically or horizontally.



6. Weld
The segments are then welded together in the welding habitat. Post-weld, the join is inspected using ultrasonic tests.



7. Retraction
Once the welded area has been signed off, the welding habitat is removed, shortly followed by the PHFs.

© Nord Stream AG; Igor Nikolajevi Pivovarov

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"Pump jacks work by drawing oil into a valved sucker rod"


A pump jack in California, USA

© Sanjay Acharya

Pump jacks explained

How do these drilling machines extract oil from deep underground?

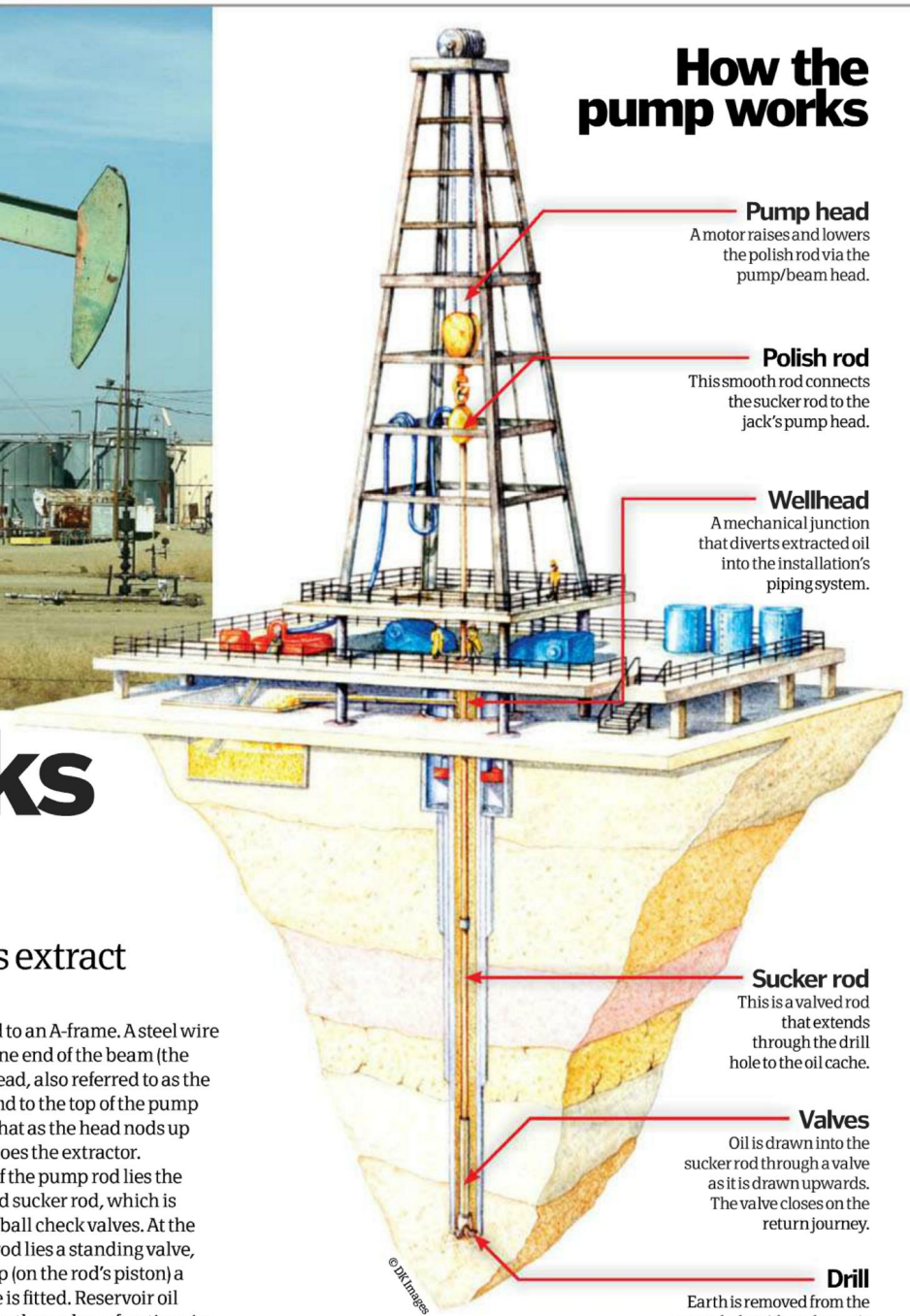
Unlike deep-sea oil caches, oil reserves under solid ground tend to be mixed in with dirt, rocks and a variety of minerals. As such, once drilled, these oil reserves do not freely ascend to the surface for collection and processing, as the bottom hole pressure is inadequate. Consequently, large extraction machines referred to as pump jacks are needed to lift the natural resource to the surface.

Pump jacks work by drawing oil into a valved sucker rod, which is extended down a drill hole by a mechanised lifting engine. The engine itself converts the rotary movement produced by an electric/diesel motor into a vertical reciprocating motion that drops and lifts a pump rod down the drill shaft. A common design for these lifting engines is the walking beam type, commonly nicknamed a 'nodding donkey' due to their physical resemblance to the creature. Here, a motor drives a pair of counterweighted cranks that, in turn, raise and lower one end of a horizontal beam mounted to an A-frame. A steel wire is attached to one end of the beam (the pump/beam head, also referred to as the 'horse head') and to the top of the pump rod, meaning that as the head nods up and down, so does the extractor.

At the base of the pump rod lies the aforementioned sucker rod, which is fitted with two ball check valves. At the bottom of this rod lies a standing valve, while on the top (on the rod's piston) a travelling valve is fitted. Reservoir oil enters the pump through perforations in the drill hole's casing and enters the standing valve. Then, when the sucker rod descends, the travelling valve is opened and oil is transferred. After transference has taken place, the standing valve is opened again to receive more oil, while the travelling valve closes for the oil's ascent to the surface.

Finally, oil is passed from the sucker rod into the pump jack's wellhead, which reroutes it into oil pipelines. The pipelines then carry the crude oil to a processing facility for refinement.

How the pump works



© DK Images


It's easy to see how these pump jacks acquired the name nodding donkeys

© Reginald Mator

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STRANGE BUT TRUE
HOUSE IN THE CLOUDS

Treetop water tower

The House in the Clouds was constructed in Thorpeness, England, as a water tower in 1923, but disguised as a house 21 metres (70 feet) up in the trees. It was used as a water tower until 1977 and it is now a popular hotel.



DID YOU KNOW? *Some buildings have their own water towers, guaranteeing pressure to fire engine hoses in an emergency*

How water towers work

These water-storage devices have kept us topped up with H_2O for centuries. But how do they perform this function?

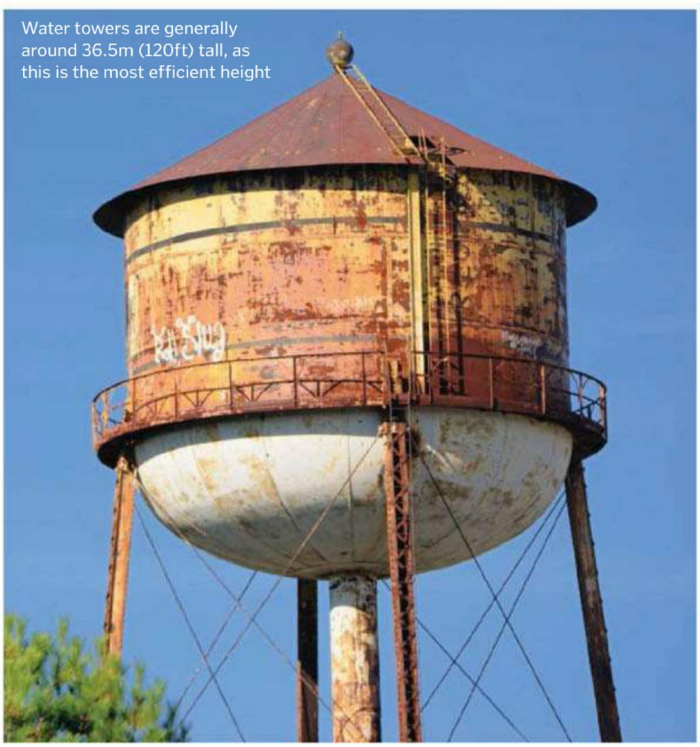
Essentially, all a water tower itself does is store water. But that's not the main purpose of this structure: it's actually a very simple and elegant solution to a real-world problem. Indeed, the basic concept has been used since before Roman times.

A water tower is used to maintain water pressure to homes, businesses and industry in a certain area, usually storing a day's worth – ie 3.8 million litres (1 million gallons) – of water. The tower itself is only built where there is no accessible point of elevation – otherwise a hill or sometimes another building is used to raise the bowser (tank) to a sufficient height.

Water towers use gravity to sustain this pressure and each 0.3 metres (one foot) of height above the level that the water is being supplied to, adds an extra 0.5 kilograms per square centimetre (0.43 pounds per square inch) of pressure. A pump attached to the mains supply at ground level pushes the water up into the tower, while the supply drains away to the consumer via a pipe in the bottom of the bowser.

Water towers come in many different shapes, sizes and materials according to the demands of their local community. Wooden towers are still widely used around the world rather than steel because they're better at insulating from extreme heat and cold, which is essential when storing water.

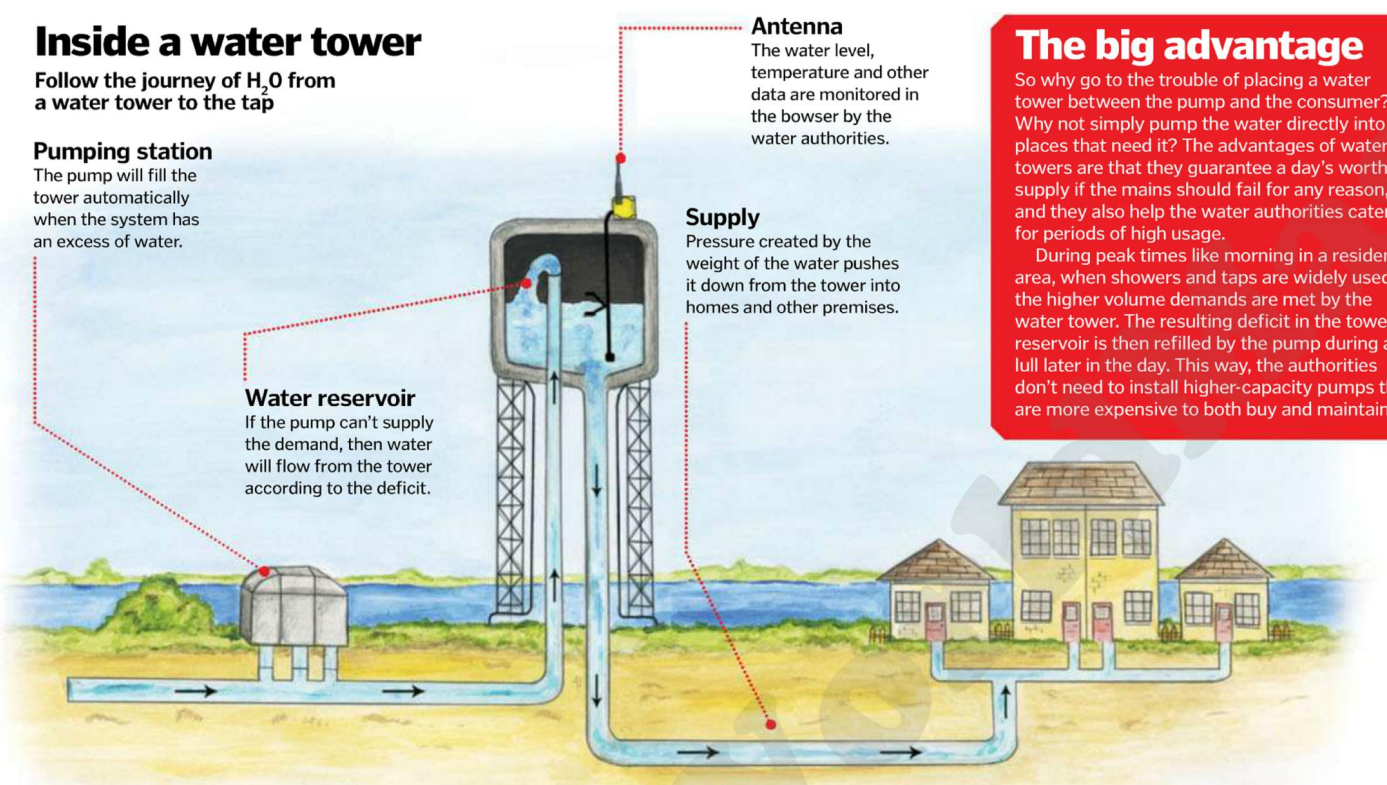
Many cities have dispensed with water towers altogether, though they're still common sights in New York where rotary pumps could damage fragile building foundations.



Water towers are generally around 36.5m (120ft) tall, as this is the most efficient height

Inside a water tower

Follow the journey of H_2O from a water tower to the tap



The big advantage

So why go to the trouble of placing a water tower between the pump and the consumer? Why not simply pump the water directly into the places that need it? The advantages of water towers are that they guarantee a day's worth of supply if the mains should fail for any reason, and they also help the water authorities cater for periods of high usage.

During peak times like morning in a residential area, when showers and taps are widely used, the higher volume demands are met by the water tower. The resulting deficit in the tower's reservoir is then refilled by the pump during a lull later in the day. This way, the authorities don't need to install higher-capacity pumps that are more expensive to both buy and maintain.

© Thinkstock; Andrew Dunn

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"Turbines are the next natural technological evolution of the water wheel"

How water turbines work

The simple technology that harnesses the immense natural power of water

Water wheels have been around for several thousand years, the concept of using water to power basic machinery like mill wheels (essentially harnessing the Earth's gravity) being well within the grasp of ancient engineers. Turbines are the next natural technological evolution of the water wheel and, although the Romans sometimes used a form of turbine for their water wheels and agricultural uses, it wasn't until the Industrial Revolution (circa 1750-1850) that the first modern turbines emerged.

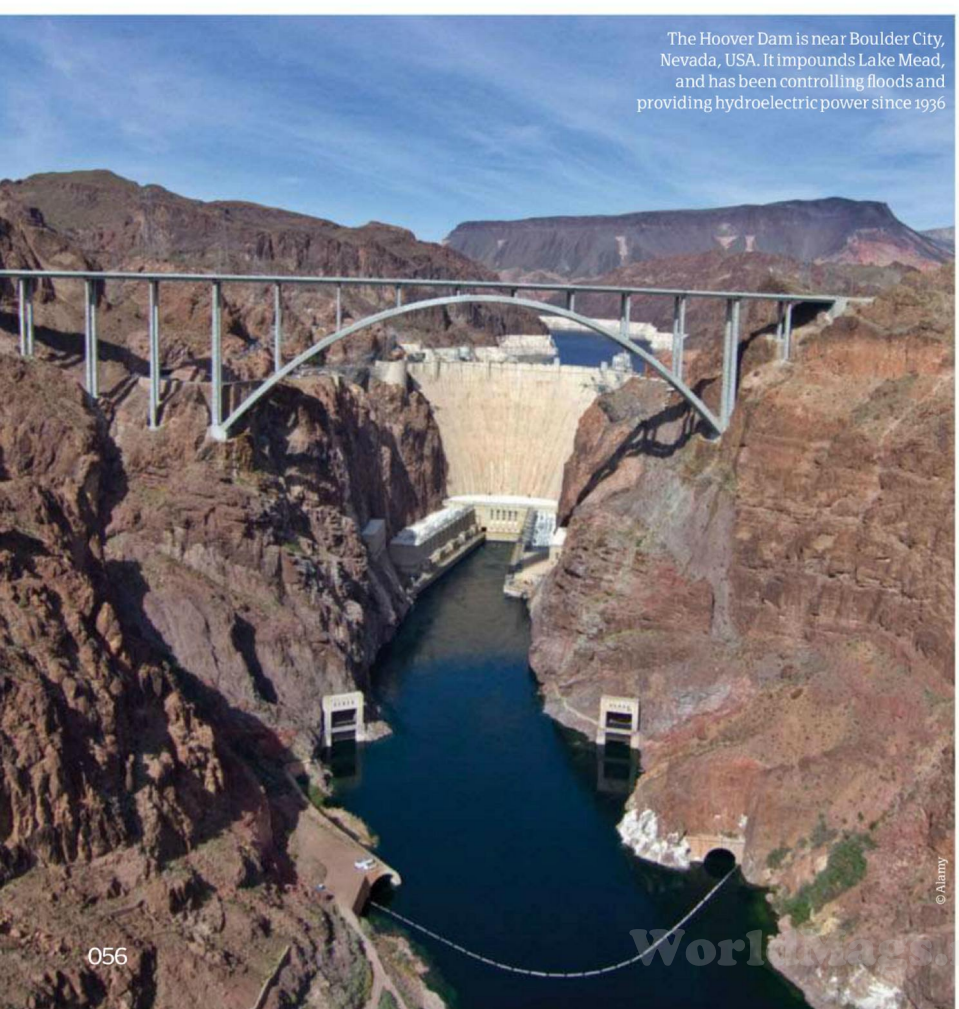
Turbines are essentially propellers in reverse, both of which work in direct accordance to Isaac Newton's third law – namely, for every action there has to be an equal and opposite reaction. In propellers, that means energy is put into a spindle of asymmetrical blades that puts pressure on the air or water, which pushes back to propel the vehicle.

Turbines are usually fixed in place, so when a fluid flows through it there is a drop in pressure at the back edge of each blade that causes the turbine to turn. The principle is the same for air or water and the faster the medium is moving, the greater the pressure drop, and the faster the turbine spins.

It's a much more efficient method than water wheels that yields greater hydraulic head (ie the amount of force the water can generate) with smaller apparatus. Historically turbines directly drove the huge factories of the 19th century, but since the dawn of electricity, they're used to generate power that can be stored or passed on to the national electrical grid for a clean and renewable source of power.

Source
Whether a lake or river, the source of water is chosen for its elevated position, from which the dam can take advantage of gravity.



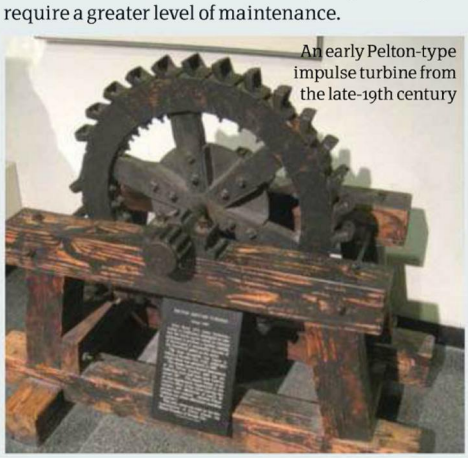


The Hoover Dam is near Boulder City, Nevada, USA. It impounds Lake Mead, and has been controlling floods and providing hydroelectric power since 1936

©Alamy

Types of turbine

There are two main types of turbine: impulse and reaction. Essentially these names describe the different blade mechanism used. In impulse turbines, where water jets onto the blades, the pressure drop (where the energy transfer occurs) takes place in the convergent guide vanes that direct the fluid onto the rotor blades. The opposite happens in a reaction turbine, where the rotor blades have convergent passages and the pressure drop happens here. Impulse turbines are usually unsuitable for low-head sites because they have low specific speeds, but they're easier to maintain. Reaction turbines, on the other hand, can rotate faster given the same head and flow conditions, but generally require a greater level of maintenance.



An early Pelton-type impulse turbine from the late-19th century

1. MICRO-POWER



© JDavis

Trzebiatów Hydro Station

Micro-hydroelectric powerplants, like the 155kW Trzebiatów Hydro Station in Poland, can be a greener option than larger dams.

2. MEGA-POWER



© Nordelphalcks

Gordon Dam

The Gordon Dam in Tasmania has a 430MW capacity, making it something of a middleweight as far as hydroelectric dams go.

3. GIGA-POWER



© Yoghq

Three Gorges Dam

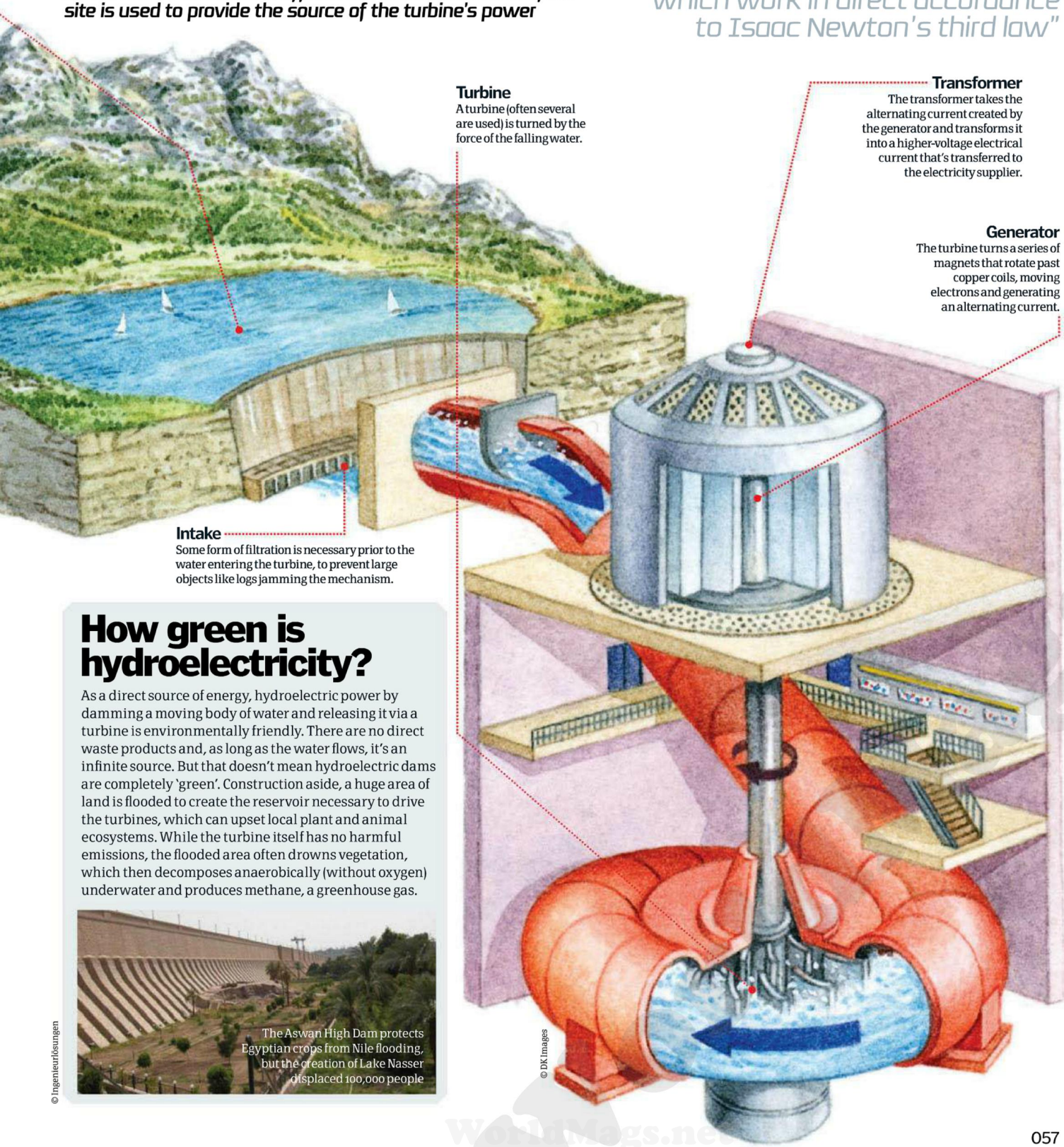
Easily the world's biggest hydroelectric powerplant is the Three Gorges Dam, which spans the Yangtze River in central Hubei, China. It can boast a staggering 18,200MW capacity.

DID YOU KNOW? *A prototype wind turbine in Abu Dhabi also creates 1,000l (265ga) of drinking water daily via condensation*

Turbines in context

A lake or river is dammed off and the natural elevation of the site is used to provide the source of the turbine's power

"Turbines are essentially propellers in reverse, both of which work in direct accordance to Isaac Newton's third law"



Turbine

A turbine (often several are used) is turned by the force of the falling water.

Transformer

The transformer takes the alternating current created by the generator and transforms it into a higher-voltage electrical current that's transferred to the electricity supplier.

Generator

The turbine turns a series of magnets that rotate past copper coils, moving electrons and generating an alternating current.

Intake

Some form of filtration is necessary prior to the water entering the turbine, to prevent large objects like logs jamming the mechanism.

© DK Images

How green is hydroelectricity?

As a direct source of energy, hydroelectric power by damming a moving body of water and releasing it via a turbine is environmentally friendly. There are no direct waste products and, as long as the water flows, it's an infinite source. But that doesn't mean hydroelectric dams are completely 'green'. Construction aside, a huge area of land is flooded to create the reservoir necessary to drive the turbines, which can upset local plant and animal ecosystems. While the turbine itself has no harmful emissions, the flooded area often drowns vegetation, which then decomposes anaerobically (without oxygen) underwater and produces methane, a greenhouse gas.

The Aswan High Dam protects Egyptian crops from Nile flooding, but the creation of Lake Nasser displaced 100,000 people

© Ingenieurlösungen

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"It stretches across 520m (1,706ft) of the Thames near Woolwich and comprises ten separate gates"

How flood barriers work

A closer look at how these mechanical defences are able to hold back great surges of water



Flood barriers are employed all over the world to prevent a sudden deluge of water from damaging property and potentially taking lives. A few sandbags lining the floor of a porch will be an effective defence against a small flash flood, but something a little more robust is required to hold back the mighty swell of London's Thames River.

In 1953, London and the surrounding area was badly hit by a flood that claimed 307 lives and caused millions of pounds' worth of damage. It prompted the creation of the Thames Barrier, an impressive feat of engineering that took eight years to build and cost £534 million ($839 million) by the time it was completed in 1982. It stretches across 520 metres (1,706 feet) of the Thames near Woolwich and comprises ten separate gates on pivots supported by concrete piers that house the machinery for operation of the gates.

As tends to be the case with all the best engineering designs, the Thames Barrier is based on a very simple concept. Each gate is radial, using hollow cylinders that rotate the barrier through 90 degrees according to whether they're in open, flood control or maintenance positions. Four central gates over 20 metres (65 feet) high and weighing 3,300 tons each span the middle section of the barrier, with two smaller gates next to them and four non-navigable radial gates that sit above the river during normal flow.

When a potential storm is forecast to hit the Thames Estuary, the barrier flood defence can be erected in around 90 minutes. Two hydraulic cylinders move rocking beams that shift the gate into the closed position. Here, the Thames Barrier can hold back the downstream tide until it's level with upstream again and safe to be opened once more.

Stormy waters

The 1953 North Sea Flood was one of the worst natural disasters to happen in the UK in recorded history. It occurred when a high spring tide combined with a severe storm over the North Sea, sending a swell that was magnified in the narrow estuarine channels along the coast. In places it reached up to 3.2 kilometres (two miles) inland, destroying 24,000 properties, 1,600 kilometres (994 miles) of coastline and flooding 1,000 square kilometres (386 square miles).

The Netherlands – parts of which lie below sea level – was even worse hit: the country's sea defences buckled under the pressure and killed 1,835 people, 30,000 animals and caused over a billion Dutch guilders (about £360 million/$570 million) of damage.

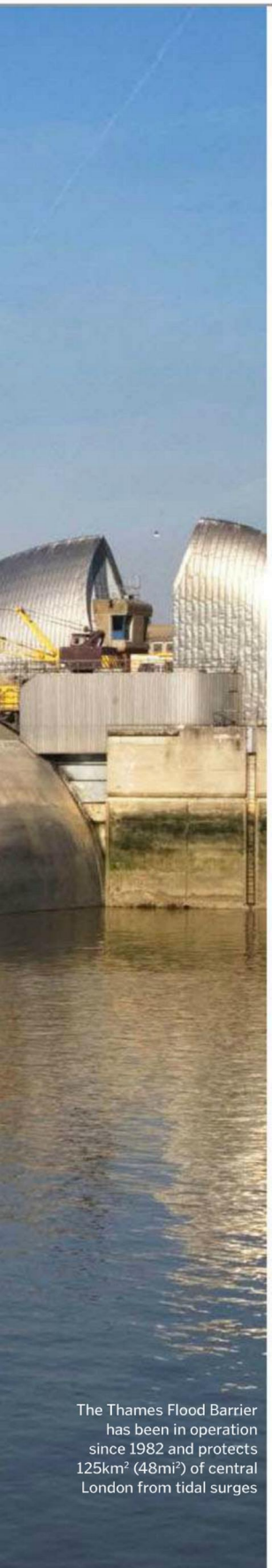
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Seesaw Britain

Britain is actually tilting, with the northern and western regions like Scotland and Wales rising, while southern and eastern parts of England are sinking into the sea by 33 centimetres (13 inches) every century.



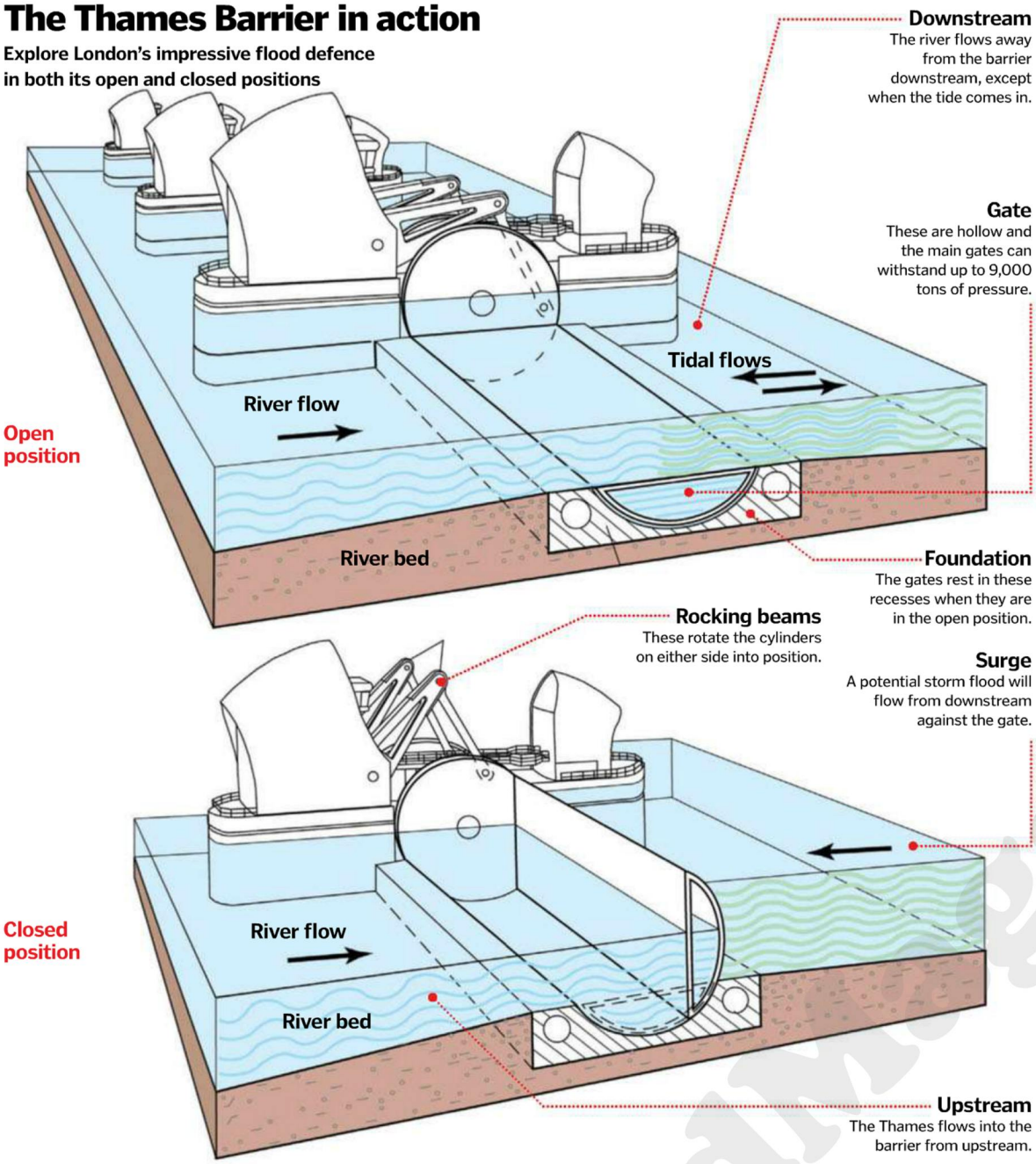
DID YOU KNOW? *The Thames Barrier was hit by a dredger in thick fog in 1997, causing £13bn ($20.6bn) of damage*



The Thames Flood Barrier has been in operation since 1982 and protects 125km² (48mi²) of central London from tidal surges

The Thames Barrier in action

Explore London's impressive flood defence in both its open and closed positions



Downstream
The river flows away from the barrier downstream, except when the tide comes in.

Gate
These are hollow and the main gates can withstand up to 9,000 tons of pressure.

Foundation
The gates rest in these recesses when they are in the open position.

Rocking beams
These rotate the cylinders on either side into position.

Surge
A potential storm flood will flow from downstream against the gate.

Upstream
The Thames flows into the barrier from upstream.

The biggest barrier

The Oosterscheldekering is the largest movable flood barrier in the world. Like the Thames Barrier, this Dutch feat of engineering was built in response to the 1953 North Sea Flood. It's actually part of 13 dams known as Delta Works and is nine kilometres (5.6 miles) long, four kilometres (2.5 miles) of which include huge sluice-gate doors that are normally open, but can be closed in the event of a tidal surge. It comprises 65 concrete pillars weighing 18,000 tons each, with 62 steel doors, each 42 metres (138 feet) wide. Dutch engineers created an artificial island in the centre of the estuary to facilitate the construction of the structure and, unlike the Thames Barrier, which is estimated to be effective until around 2030, Oosterscheldekering has a predicted lifetime of 200 years.



© Alamy; Thinkstock; Rens Jacobs; John Webber

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"Gas welding produces a welding flame of 3,100°C (5,612°F)"


A US Navy engineer in the process of arc welding

What is welding?

The processes and technology of this manufacturing cornerstone explained

Welding is a process in which metals and thermoplastics are joined together to produce an object or structure. These materials are commonly joined by the melting of a filler material, such as steel, at their boundary points, fusing them together. There are three main techniques: gas welding, arc welding and laser welding.

Gas, or oxy-fuel, welding, is the most common type and also the oldest. This process works through the combustion of acetylene in an oxygen stream, with the gas funnelled to a point of focus (ie the welding stick – this can be a handheld or stationary robotic applicator), where it is ignited to produce a high-temperature flame. Gas welding produces a welding flame of 3,100°C (5,612°F) and, as such, is typically used to weld high-alloy steels. However, the flame produced in a gas-based system is typically less concentrated than other methods, leading to greater weld distortion.

Arc welding differs to gas welding significantly. This technique involves melting the work materials through an electrical arc. This is generated by attaching a grounding wire to the welding material and then placing another electrode lead against it, itself attached to an AC/DC power supply. When the electrode lead is drawn away from the materials it generates an electrical arc (an ongoing plasma discharge caused by the electrical breakdown of gas), which through its expelled heat, fuses the materials. Unlike gas welding, arc welding produces a more concentrated weld point.

Finally, laser welding – which is one of the newest forms of welding – uses a high-energy beam to meld materials. As the laser has a high-energy density, this technique can achieve a deep penetration and incredibly focused weld, with little surrounding distortion. Due to this, laser welding is commonly used in large industrial applications, where speed and finesse are of great importance.

Swimming machines

How do these endless pools enable you to swim forever?



Swimming machines can be installed in the home

An endless pool is essentially a treadmill for swimmers. Rather than using a full-size pool, swimmers are able to exercise constantly – without having to stop and turn round – by using a water treadmill. Invented in the Eighties, endless pools are typically up to 3m long and 1.8m deep (10ft long and 6ft deep). Water is propelled out from the front end and swimming into it is like swimming in a river, allowing for an endless swim.

The current that is produced at the front end is wider than the swimmer's body, so that they get significant resistance in order to prevent them from moving forwards as the water moves over their body. A hydraulic motor powers a 40cm (16in) propeller that shoots the water out, with the cyclic power of 5,000 gallons per minute. Once it reaches the end of the pool, the water then falls into two grills that channel water back to the front, allowing the cycle to continue.

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How many of these items fit into this man-made hole?

30 BILLION HOPE DIAMONDS


© 390233

2 MILLION LONDON BUSES


© Thinkstock

22 THOUSAND GREAT SPHINXES


© Barcex

DID YOU KNOW? *Flying over the Mirny mine is prohibited as several aircraft have been sucked into it by powerful downdrafts*

How are diamonds mined?

Peer into the second-largest excavated hole in the world in search of treasure...

The Yakutia area of Siberia is one of the coldest and most inhospitable places on Earth. Temperatures of -20 degrees Celsius (-4 degrees Fahrenheit) are common during the winter months and night-time temperatures can plummet so low that oil freezes and steel becomes brittle. Hardly ideal living conditions but it's here, just outside the Arctic Circle, that the town of Mirny sprung up after the discovery of a large kimberlite field in 1955. Why is this worthless igneous rock so important? It's because kimberlite is known to sometimes contain diamond 'pipes'.

The Mirny mine in particular was significant because, up until then, the USSR essentially had no diamond industry. Within a few years this single mine proved such a rich source of diamonds that during the Sixties it was accounting for 10 million carats of the world's diamond industry, which in everyday weight equates to roughly 2,000 kilograms (4,409 pounds) of these precious gems.

Mirny was an open-pit mine up until its last decade of operation. This type of open-cast mining is used when valuable deposits are found close to the surface where tunnelling would be unsafe due to the soft overburden (ie the material above). The mine starts by scraping the topsoil and overburden away to expose the valuable deposits. Mirny was systematically excavated to a depth of over half a kilometre (0.3 miles) in ever-decreasing concentric circles, with the richest diamond-bearing seams found in the upper layers down to around 340 metres (1,115 feet). The open-cast mining method was dispensed with in 2001 and tunnels were dug to retrieve the remaining gems still cost-effective using this method. The Mirny mine was closed in 2011 and the bottom filled with 45 metres (150 feet) of rubble to prevent the pit from collapsing.



Just under 50 per cent of diamonds mined annually come from South and Central Africa



ON THE MAP

Diamond mines around the globe

1. Mirny mine, Russia
2. Panna mine, India
3. Diavik mine, Canada
4. Argyle mine, Australia
5. Magna Egoli mine, Sierra Leone
6. Baken mine, South Africa

Opened in the Fifties, the Mirny mine was officially shut down in 2011

2x © Reuters/Corbis

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"Dynamite is used to blast through the rock surrounding gold deposits"

Gold mining

From impervious rock to precious metal, how is gold extracted and processed?

Gold has been sought after worldwide for centuries due to its value to the human economy, not to mention its intrinsic beauty. Its face-centred cubic crystal structure and soft and malleable nature mean that it is the foremost material used in the jewellery industry, being shaped into a wide variety of decorative items. Unfortunately, while handling gold is easy, acquiring it is not, with numerous highly scientific processes and technological machines needed to find, mine and process it.

Native gold – as found within gold ores – occurs both at the Earth's surface (exogenetic) and underground (endogenetic), with each iteration requiring differing techniques to acquire and process it. The majority of exogenetic gold exists as alluvial gold deposits. Alluvial gold is that found in riverbeds, streambeds and floodplains, where surrounding rock and metals from its ore have been washed away. This type of gold is processed by passing deposits over jigging conveyor belts, which free the denser gold from the less-dense sand and gravel.

Unlike the easily accessed exogenetic alluvial deposits, endogenetic deposits are much harder to extract and process. This is because endogenetic deposits often contain elemental gold finely disseminated within a base metal sulfide material, literally encapsulated within a rocky prison (the ore). To free this fine particulate gold, two main methods are used: amalgamation and cyanidation.

Amalgamation works by passing a slurry of ore over copper plates coated with mercury. By doing this, the elemental gold is wetted and dissolved, forming an alloy called 'amalgam'. The amalgam is then separated from the now-barren ore in a mill discharge before being heated to distil off the mercury, leaving nothing but the now-free gold. The cyanidation process is similar to amalgamation, but a little more complex. Here the gold ore is oxidised and dissolved in an alkaline cyanide solution. This process causes the formation of sodium cyanoaurite and sodium hydroxide, and allows a gold-bearing solution to be separated from the worthless ore solids.

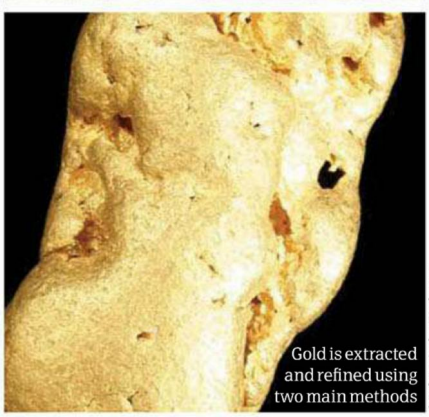
Refining gold is a necessary step to ensure purity, as extracted endogenetic gold commonly contains a number of impurities such as iron and copper. As with the extraction process, it relies on two main methods: the Miller process and the Wohlwill process. The Miller process involves the extracted gold being melted and mixed with gaseous chlorine. This causes the impurities in the gold – which bond easier with the chlorine than the gold does – to form chloride compounds that separate into a layer on the gold's surface. These are then easily removed. The Wohlwill process, meanwhile, uses electrolysis to achieve a separation of impurities. Here, gold is lowered into an electrolyte solution and an electric current is passed through. Under the influence of the current, the impurities pass into it and sink to the bottom of the tank as an insoluble slime, leaving the gold free and pure.


The Grasberg gold mine in Papua, Indonesia, is the largest in the world, covering 24,700 acres

© Alfindra Primaldhi

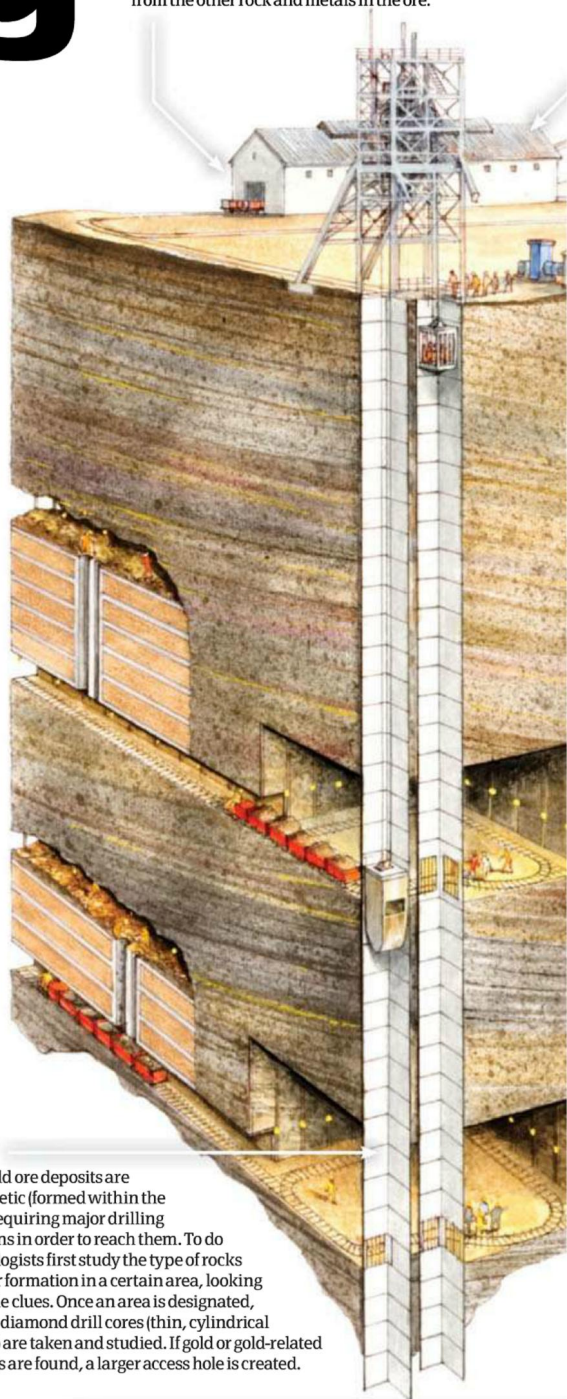

Twin dump trucks load ore in an underground gold mine

© Science Photo Library


Gold is extracted and refined using two main methods

© Rob Lavinsky, iRocks.com

4. Processing
Once the deposits are brought to the surface, the ore is ground into a fine powder and added to a cyanide solution. The solution combined with the oxygen in the air dissolves the gold, freeing it from the other rock and metals in the ore.



1. Drill
Major gold ore deposits are endogenetic (formed within the Earth), requiring major drilling operations in order to reach them. To do this, geologists first study the type of rocks and their formation in a certain area, looking for telltale clues. Once an area is designated, multiple diamond drill cores (thin, cylindrical samples) are taken and studied. If gold or gold-related materials are found, a larger access hole is created.

3. Extraction
Removing the gold ore from under the ground requires a host of expensive machinery and equipment. To access the deposits, dynamite is needed to blast through the surrounding rock, which in turn needs to be hauled out of the mine by large mechanical cranes and trucks. Electricity is also needed, both to power artificial lights as well as pump oxygen throughout.

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5 TOP FACTS MINING FOR GOLD

Native
1 Native gold is the most common mineral of gold in the Earth's crust, accounting for 80% of its total. The largest complete nugget of native gold found weighed 92kg (203lbs).

Distribution
2 Currently, 50% of the world's gold reserves are in South Africa, with the other 50% distributed over Brazil, Canada, Russia, Australia and the US.

City of Gold
3 Johannesburg is named the 'City of Gold' due to its mining industry. The largest gold resources in the world run through the Witwatersrand metropolitan area of the city.

Jewels
4 In the jewellery industry, gold content is specified for karat, with each karat equal to 4.2% gold content. Pure gold is 24 karats, the most valuable and prestigious form in jewellery.

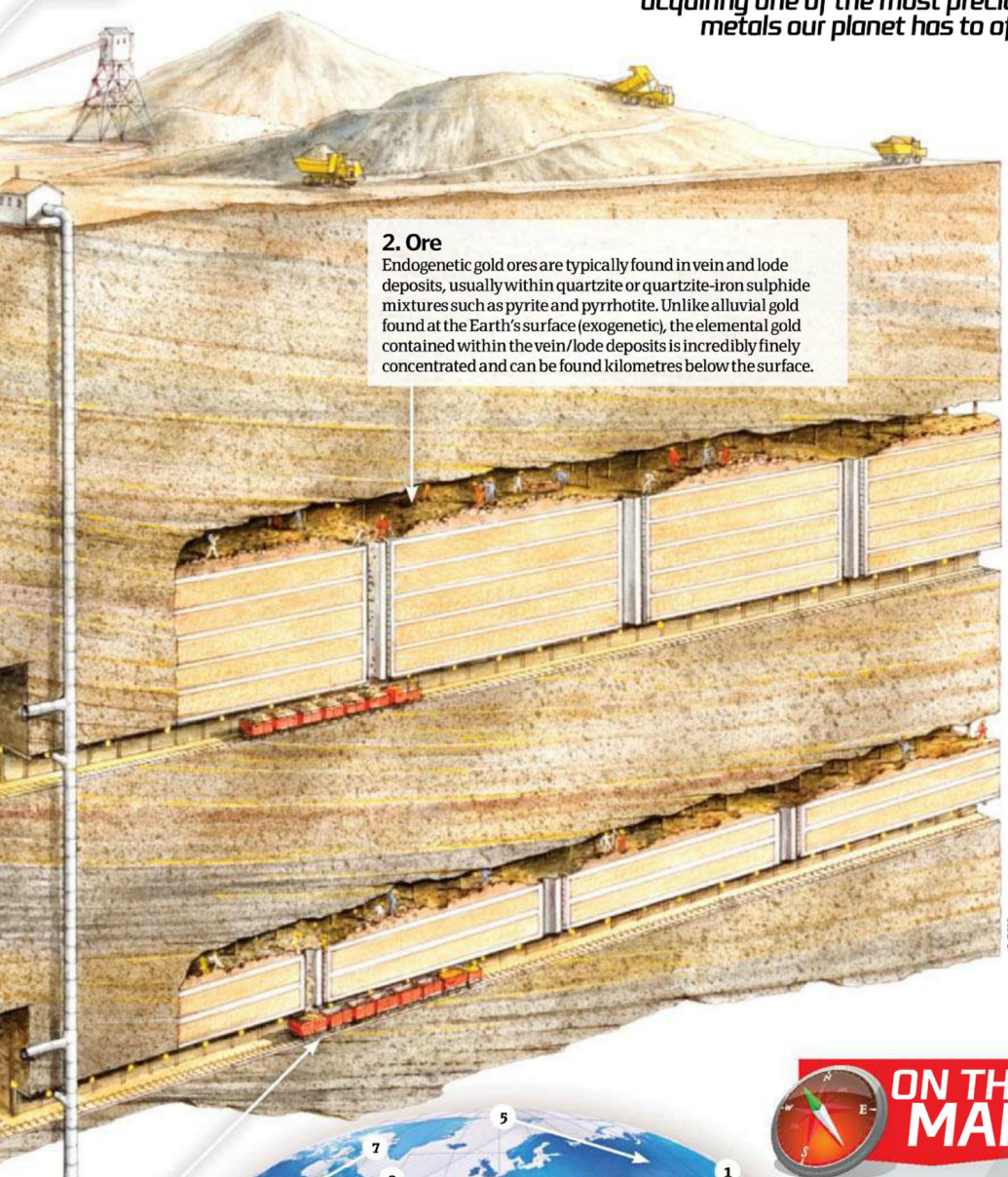
Soft
5 Pure gold – as used for gold bars – is incredibly soft as a metal. Where gold is used in other products, it is alloyed with another metal to provide hardness and strength.

DID YOU KNOW? *Gold melts at a temperature of 1,064°C (1,947°F)*

5. Refine
Gold extracted by amalgamation or cyanidation contains impurities. To remove these, two methods of refining are used. The first uses chlorine gas to filter out the gold's impurities, bonding with them once the gold is melted. The second method uses electrolysis, turning the impurities into insoluble slime.

Underground gold mining

From this incredible cutaway you'll discover the five key stages in acquiring one of the most precious metals our planet has to offer



2. Ore
Endogenetic gold ores are typically found in vein and lode deposits, usually within quartzite or quartzite-iron sulphide mixtures such as pyrite and pyrrhotite. Unlike alluvial gold found at the Earth's surface (exogenetic), the elemental gold contained within the vein/lode deposits is incredibly finely concentrated and can be found kilometres below the surface.

© DK Images

ON THE MAP



Top ten gold producers worldwide
1 China – 313 tons
2 Australia – 227 tons
3 United States – 216 tons
4 South Africa – 205 tons
5 Russia – 204 tons
6 Peru – 180 tons
7 Canada – 95 tons
8 Indonesia – 90 tons
9 Ghana – 90 tons
10 Uzbekistan – 80 tons

Panning for gold

Check out how to perform the oldest mining technique in the book

STEP 1
Locate gold country



Locating a 'gold' area requires a study of geography and geology. Riverbanks and streams are good places to start, as placer deposits can form in them during sedimentary processes. These deposits contain alluvial gold, which forms in the rivers and streams due to their low velocity compared with the gold's density.

STEP 2
Knead



Once a gold area has been located, take your gold pan and submerge it, scooping up part of the riverbed. Once filled with debris, knead the contents to break it up fully and ensure the materials are saturated with water. A lot of mud and silt will rise to the surface and get washed away, as well as any leaves and roots.

STEP 3
Shake, shake, shake



Once the pan's contents are saturated, grip it in both hands and shake it from side to side just under the water's surface. You'll break down the contained materials further, freeing them of dirt and miscellanea as well as causing the heavier materials to sink to the bottom. Any overly large objects such as rocks will also stand out from the debris. When this happens, remove them from the pan by hand.

STEP 4
Rinse and repeat



Continue to shake the pan and sweep the top layer of materials away. The remaining materials should get smaller and darker until you're left with a dense black sand. This consists of the heaviest materials left in the pan. This is the point to check how rich the area's gold content is. Taking a little bit of water in the pan, gently swirl the materials. This will cause any gold at the bottom to become visible.

STEP 5
Harvest



If flakes or small nuggets of gold are present, drain off the water and apply a magnet to the sands. This will help remove the worthless metals and reduce the black sand covering the gold. Finally, once the gold flakes or nuggets are visible, use a pair of tweezers to place them in a collecting jar.

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"They can be configured to bore through a surprising variety of materials"



MEGA DRILLS

Burrowing through a mountain range requires a little more digging power than a couple of pickaxes. Here, we take a closer look at the giants of the tunnelling world

Tunnel-boring machines (TBMs) – sometimes known as 'mega-moles' within the industry – are pieces of drill-mining equipment used to excavate long tunnels, such as those used by cars and trains in hilly and mountainous regions. They can be configured to bore through a surprising variety of materials, ranging from sand, through to earth and even solid rock.

Each tunnel-boring machine consists of three key components: a cutterhead, hydraulic bracing system and an excavating conveyor, as well as a host of other elements (see 'Tunnel-boring machine breakdown' overleaf for details).

The cutterhead comprises a circular metal face interspersed with discs that, when the cutterhead rotates – and it can turn a full 360 degrees – are forced against the tunnel face under immense pressure. In this process the cutter discs roll over the surface, loosening the material – whether it's rock or soil – into small segments referred to as chips. As the chips are created, they fall into large bucket lips, which are openings in the cutterhead that lead to a series of sheltered hoppers. Once the hoppers receive the excavated material they discharge it onto a vast conveyor belt system that extends backwards through the central body of the tunnel-boring machine.

At the rear of the TBM the belt deposits the material into a back-up area, which tends to be an enlarged cavern within the tunnel system with access to the surface. Here the chips are scooped up by a tracked or wheeled loading unit and placed into a 'muck truck', a large dump vehicle that specialises in traversing the tunnel system to the surface where the material can be dropped off for further processing or relocation.

Importantly, the overall extraction process greatly relies on a TBM's ability to remain stable within the tunnel it is mining. This is made possible due to radially mounted hydraulic braces, which are fixed to the mega drill's body, pushing outwards into the tunnel's walls. These braces simultaneously stabilise

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KEY DATES
GOTTHARD BASE TUNNEL (GBT)

1999 – Excavating activities begin for the GBT with blasting works starting at Sedrun, Switzerland.

2003 – After being awarded the contract, Herrenknecht delivers four Gripper TBMs and begins drilling.



2006 – The Gripper TBMs on the northern and southern sections reach their first target nine months ahead of schedule.

2009 – Mechanised tunnelling is completed in the north.

2010 – The main breakthrough of the eastern tunnel is completed between Sedrun and Faido.

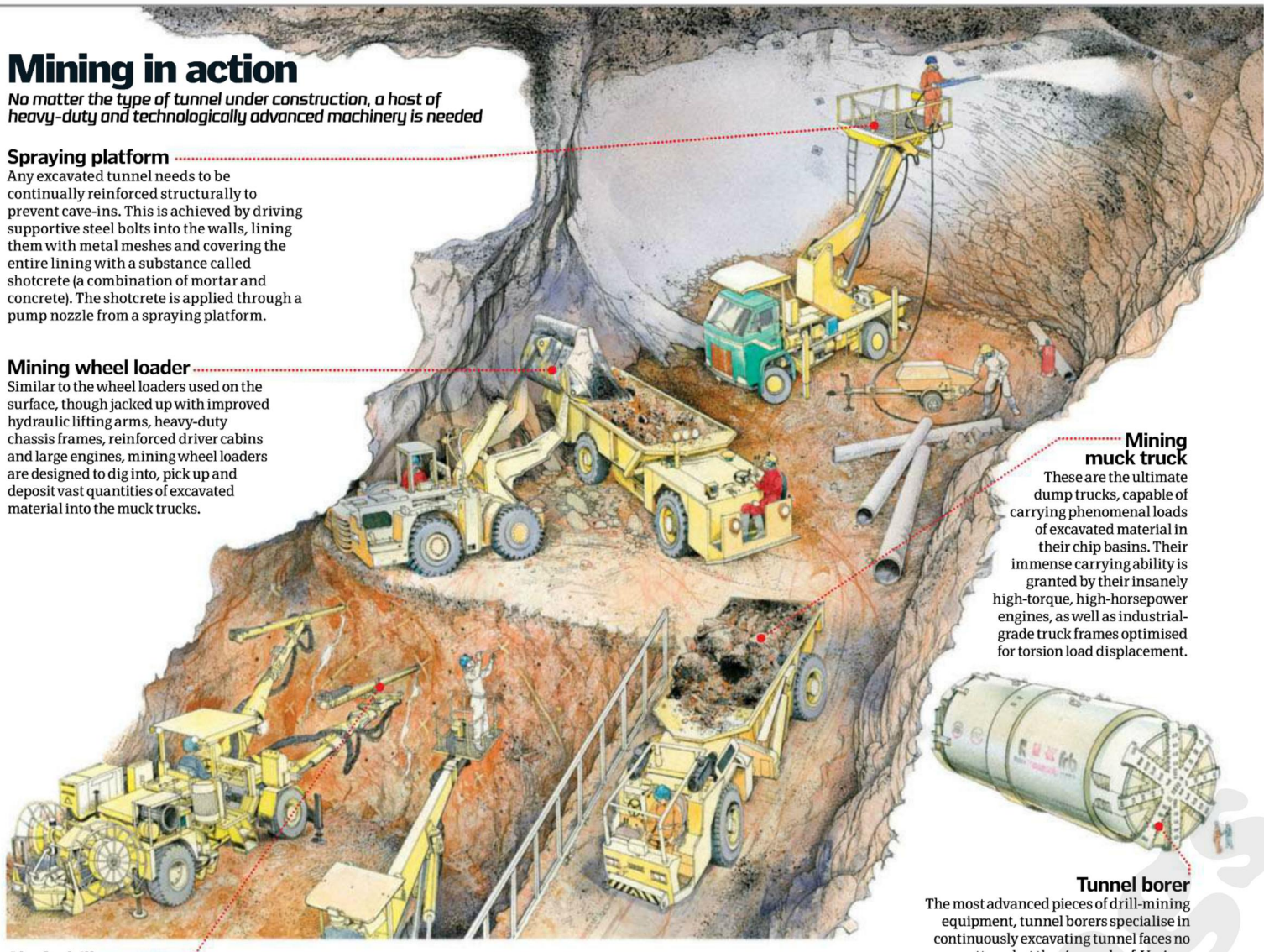


2011 – The main breakthrough of the western tunnel is completed between Sedrun and Faido.

DID YOU KNOW? *The first railway tunnel through the Gotthard region was completed in 1882*

Mining in action

No matter the type of tunnel under construction, a host of heavy-duty and technologically advanced machinery is needed



Spraying platform
Any excavated tunnel needs to be continually reinforced structurally to prevent cave-ins. This is achieved by driving supportive steel bolts into the walls, lining them with metal meshes and covering the entire lining with a substance called shotcrete (a combination of mortar and concrete). The shotcrete is applied through a pump nozzle from a spraying platform.

Mining wheel loader
Similar to the wheel loaders used on the surface, though jacked up with improved hydraulic lifting arms, heavy-duty chassis frames, reinforced driver cabins and large engines, mining wheel loaders are designed to dig into, pick up and deposit vast quantities of excavated material into the muck trucks.

Mining muck truck
These are the ultimate dump trucks, capable of carrying phenomenal loads of excavated material in their chip basins. Their immense carrying ability is granted by their insanely high-torque, high-horsepower engines, as well as industrial-grade truck frames optimised for torsion load displacement.

Tunnel borer
The most advanced pieces of drill-mining equipment, tunnel borers specialise in continuously excavating tunnel faces no matter what they're made of. Various types are manufactured ranging in size, length and material expertise (eg sand, earth, rock, etc). The largest TBM in the world has a cutterhead 19.3m (63.3ft) across!

Shaft drill
These allow their operator to use a series of drill shafts/booms to penetrate tunnel faces with acute precision. The drills – which are akin to manual jackhammers – extend from the vehicle's body on long hydraulic arms and, powered pneumatically, drive their drill bits into the rock/earth to break it up.

its position so it can push forward, while also supporting the structure of the tunnel. Once braced, a series of hydraulic cylinders extend from the TBM's body and press the cutterhead's disc cutters firmly against the tunnel face, allowing a new stretch to be cleared.

While drill mining is, of course, the primary purpose of a TBM, it also acts as a platform for many of the safety procedures needed to secure a tunnel during the building process.

These include installing rock anchors, metal meshes, steel beam supports and, at the rear of the TBM, the necessary pumps and nozzles required to inject shotcrete – a mortar/concrete wet mix used to line and reinforce tunnel walls. All these tasks are performed in the 'working area' of the TBM, a large segment positioned just behind the cutterhead where ring erectors, anchoring drills and wire-mesh installers semi-automatically secure a freshly excavated tunnel to make it safe for tunnel workers to proceed.

Boring history

Prior to mechanised boring machines, tunnels were made through a mixture of explosives and manual labour, with men and machine alike locked in an incredibly dangerous game of knock and run. The introduction of the first boring machines didn't improve things much either, with the early systems relying on water compressors to supply them with pressurised air to drive their drills into the earth. The machines broke down frequently and, due to their cumbersome and inaccurate nature, led to many accidents deep within mountain excavations.

Other early systems, such as the 1853 Wilson's Patented Stone-Cutting Machine, just failed to work at all. Famously, engineer Charles Wilson's contraption, which had been employed to help drill out the Hoosac railroad tunnel in Massachusetts, USA, cut through just three metres (9.9 feet) of rock before breaking and falling to bits. The tunnel was eventually completed 20 years later using traditional methods and it, as well as the remains of Wilson's machine, can still be seen there to this day.



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"Each TBM has three key parts: a cutterhead, hydraulic bracing system and excavating conveyor"

Boring the Gotthard Base Tunnel

Officially the world's longest railway tunnel, the GBT stretches a total 152km under the Swiss Alps. Here we look at how this engineering marvel was built...



Record breaker

Due to the vast cutterhead diameter of the Herrenknecht Gripper TBMs, in 2008 a new world record was set by a northern unit, drilling through 56m (184ft) of earth between Erstfeld and Amsteg in 24 hours. What's more, when the TBM in question made the breakthrough into the Amsteg tunnel centre, it had only deviated from the ideal drill line by 4mm (0.15in) horizontally and 8mm (0.3in) vertically!



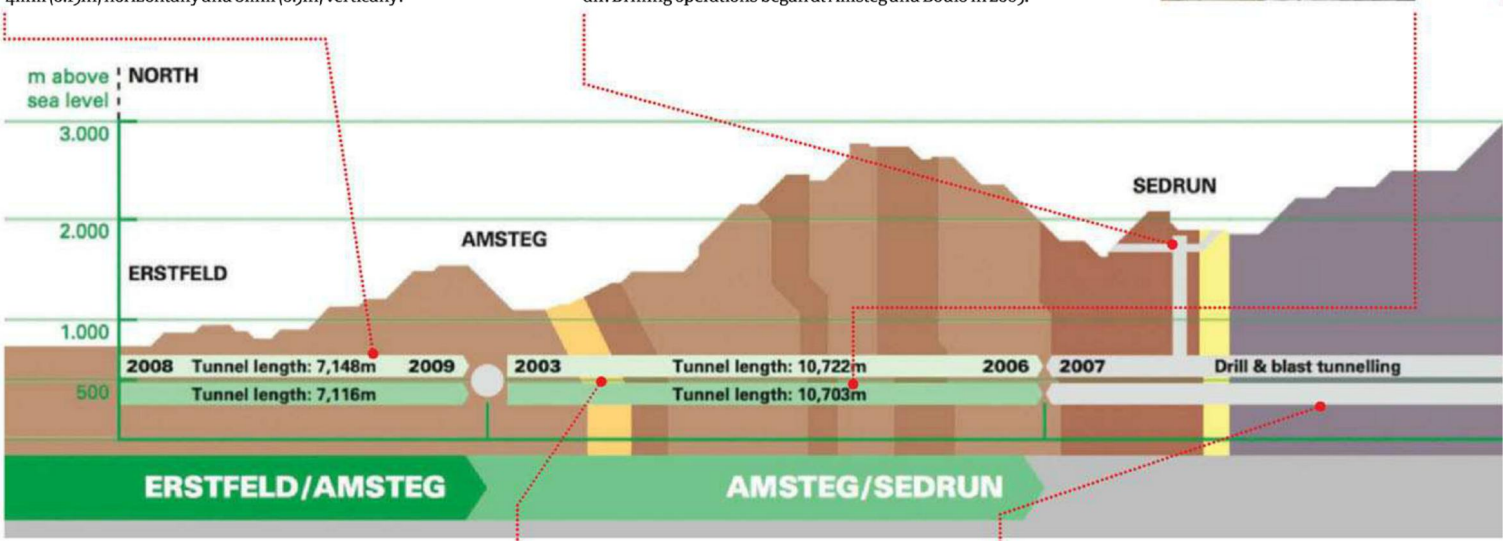
Fire in the hole!

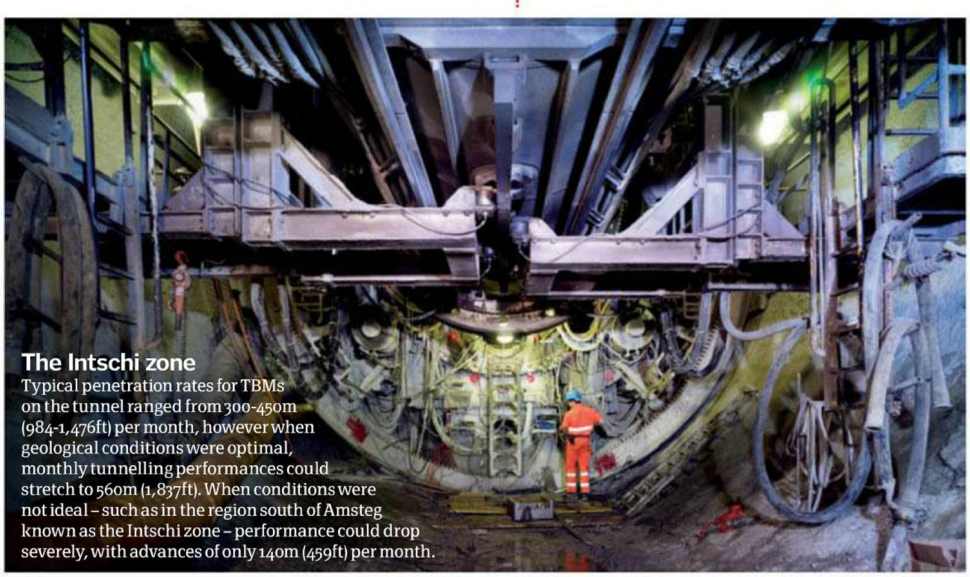
Tunnel construction began proper in 1999 at Sedrun, a small settlement 1,405m (4,610ft) above sea level. From here engineers set up a construction control centre and began blasting operations. This allowed large access and supply tunnels to be excavated down to the tunnel's position, as well as a ventilation shaft for the supply of fresh air. Drilling operations began at Amsteg and Bodio in 2003.

Water logged

In 2005 the engineers in the western tube hit the longest delay of the project due to a combination of loosened rock and mountain water suddenly infiltrating the cutterhead. After a failed attempt to clear the cutterhead by hand, engineers had to solidify the loose soil ahead by injecting it with cement and bentonite. The cutterhead was eventually cleared and, five months later, boring resumed.

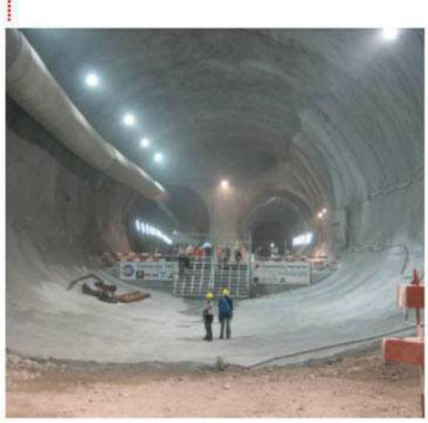






The Intschi zone

Typical penetration rates for TBMs on the tunnel ranged from 300-450m (984-1,476ft) per month, however when geological conditions were optimal, monthly tunnelling performances could stretch to 560m (1,837ft). When conditions were not ideal – such as in the region south of Amsteg known as the Intschi zone – performance could drop severely, with advances of only 140m (459ft) per month.



Zurich to Milan

With drilling operations now complete the tunnel is set to be fully equipped and ready for its public opening in 2017. When opened the Gotthard Base Tunnel will enable passengers to travel from Zurich, Switzerland, to Milan, Italy, in just two hours 40 minutes, which is a whole hour less than the current route allows.

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GO FIGURE
GBT IN NUMBERS

How many of these could fit end-to-end in the world's longest railway tunnel?

23 THOUSAND ANACONDAS



13 THOUSAND NARROWBOATS



345 TUNNEL-BORING MACHINES



DID YOU KNOW? *Trains will travel at up to 250km/h (155mph) through the Gotthard Base Tunnel*

Epicentre
Both main breakthroughs – the joining up of the north and south excavations – occurred in 2010 and 2011, respectively, at the epicentre of the tunnel, about 28km (17.5mi) from either end. Deep within the Swiss Alps, and under more than 2,000m (6,562ft) of rock, the joining of both east and west tunnels was a momentous achievement for all those involved and marked the end of the drilling operation.

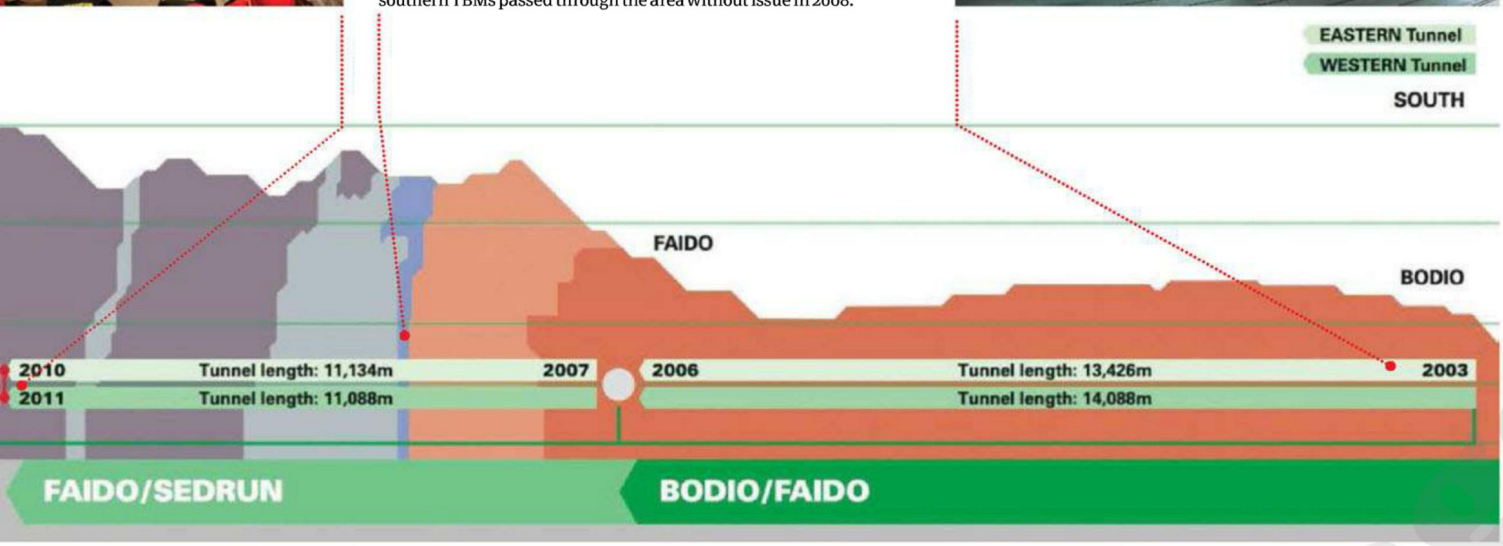




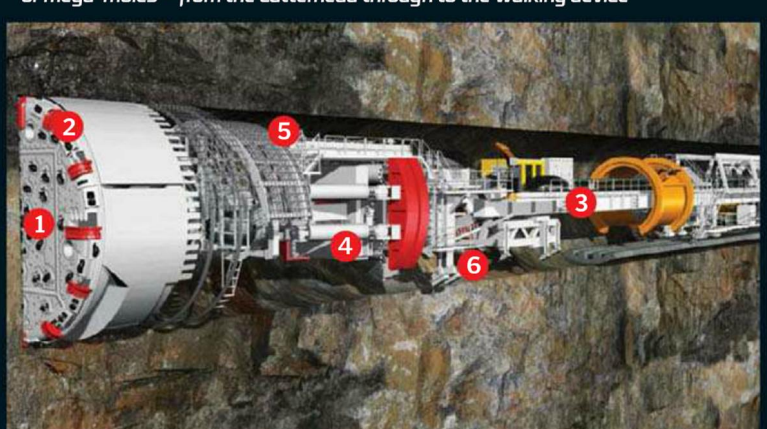
Devil's basin
Not far from Faido lies the Piora Basin, a funnel-shaped region consisting of sugar-grained dolomite and water, under a huge pressure of 150 bars. When inclined drills were used to probe the area back in 1996, a deadly jet of water and dolomite exploded out. This led to speculation that boring through the area could be immensely dangerous. Luckily, after reports came through that the basin culminated in a gypsiferous cap-rock above the tunnel's depth, both southern TBMs passed through the area without issue in 2008.

Kakirite zone
The two southern tunnel-boring machines that began drilling at Bodio hit a major obstacle after only 200m (660ft) of operation, running into a geological disturbance region known as a kakirite zone. This area was made of material too soft for the Gripper TBMs to process as usual, which specialise in drilling through hard rock. As such, every metre of the tunnel that was excavated needed to be reinforced prior to boring.





Tunnel-boring machine breakdown
Get to grips with the key components of these burrowing behemoths – or mega-moles – from the cutterhead through to the walking device



1. Cutterhead
All the excavation tools are mounted in the cutterhead at the front of the TBM, which also supports the tunnel face.

2. Disc cutters
These roll in concentric circles over the tunnel face. The contact pressure crushes the rock/earth.

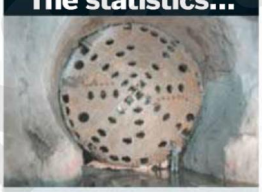
3. Conveyor belt
The system's buckets deposit the excavated rubble behind the cutterhead onto a conveyor belt system.

4. Thrust cylinders
These drive the rotating cutterhead against the tunnel face.

5. Roof bolting unit
This part can rotate around the machine's axis and drills holes into the rock for receiving metal bolts.

6. Walking device
The rear of the bore and the back-up systems rest on these moving feet.

The statistics...



Gotthard Base Tunnel

Construction start: 2003

Maximum altitude above sea level: 550m (1,804ft)

Total length of tunnels/ shafts: 151.8km (94.4mi)

Tube diameter: 8.8-9.6m (29-31ft)

Maximum overburden: 2,500m (8,200ft)

Tunnel borers: 2 x south / 2 x north (Herrenknecht Grippers)

Construction end: 2016

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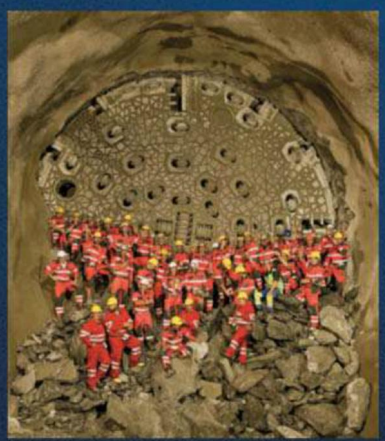
"The largest of these cutterheads is a 15.2-metre (49.8-foot)-across Herrenknecht-brand EPB Shield"

World's largest drill

Our inability to make inroads into some of Earth's most impenetrable terrain was a problem once... then they built tunnel-boring machines!

Tunnel-boring machines are designed to drill large-scale excavation holes into terrain that would otherwise be difficult or even impossible to penetrate. They are commonly used in the construction of underground tunnels and bypasses – modern motorway and train tunnels are often built with them – and they are specially designed not just to cut through rock and earth, but crucially to support the tunnel in the process. Additionally, today's most advanced boring machines are engineered to remove debris as it is generated by the drilling process, with rocks and rubble transported to the rear of an assembly on conveyor belts for easy disposal.

Key to any tunnel-boring machine though is its colossal cutterhead, a cylindrical wall of disc cutters and drills that – in partnership with extreme pressure, which is generated by the bore's thrust cylinders – literally crush any material that sits in its path. The largest of these cutterheads currently in operation is a 15.2-metre (49.8-foot)-across Herrenknecht-brand EPB Shield, a record-breaking piece of machinery that was used to carve out chunks of earth in the construction of Madrid's M-30 motorway north tunnel. As you can see on this page, the total assembly is huge and it weighs hundreds of tons.



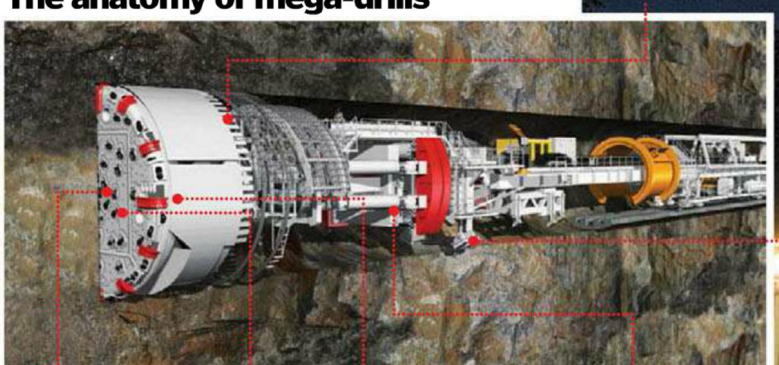
Engineers, along with a large tunnel-boring machine, celebrate after completing the western tube of the Gotthard Base Tunnel in Amsteg, Switzerland. The tunnel will be a new world record in length once it's completed

Roof bolting unit
This part can rotate around the machine's axis and drills holes into the rock for supporting metal bolts.

Walking device
The rear of the bore and the back-up systems rest on the feet of the walking device. They are lifted as tunnelling progresses and the back-up system follows.

Thrust cylinders
These press the rotating cutterhead against the tunnel face.

The anatomy of mega-drills



Cutterhead
All the excavation tools are mounted in the cutterhead, which also supports the tunnel face.

Disc cutters
These are mounted in the cutterhead and roll in concentric circles over the tunnel face. The contact pressure crushes the rock.

Buckets
The system's buckets transport the excavated rubble behind the cutterhead onto a conveyor belt system.

DID YOU KNOW? *A tunnel-boring machine excavated 10.5 million cubic metres of rubble to carve the Gotthard Base Tunnel*



What is it?

This image shows a record-breaking tunnel-boring machine (15 metres/50 feet across) in the heart of Madrid, Spain. The titanic bore was used in the construction of the city's M-30 motorway north tunnel.

All images © Herrenknecht AG

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Hoover Dam construction

It was one of the most ambitious projects in the world, but how was the Hoover Dam constructed, and why was it ever deemed necessary?

In the early-20th century, the lower region of the Colorado River was considered as a site for flood control and potential source of hydroelectric power for the growing demands of western US states. What would be known as the Hoover Dam was authorised by President Calvin Coolidge in 1928 and construction began by building conglomerate Six Companies in March 1931.

At the time the Hoover Dam was the largest in the world requiring over 3.3 million cubic metres (118 million cubic feet) of concrete to build, including the power station.

Before the dam could be built, foundations had to be laid and over 1.3 million cubic metres (48 million cubic feet) of loose rock and sediment were removed from the bottom of the Colorado River to reach stable bedrock. The foundation was reinforced with a grout curtain and the canyon walls were similarly stabilised by drilling holes up to 46 metres (150 feet) deep into them and filling cavities with more grout. Chief engineer John Savage had decided it would be an arch-gravity dam, which combines the main features of two different types of dam: the arch part is a concave face that leans towards the water, deflecting some of the pressure onto the canyon walls, while the gravity part of the design is the enormous weight of the dam that thickens considerably from the top (13.7 metres/45 feet) to the bottom (201 metres/660 feet). This helps to resist the immense force that the Colorado River can generate with its 5.5 million-ton weight.

To help dissipate the heat generated by all this concrete setting, around 950 kilometres (590 miles) of steel piping delivered water cooled by the dam's dedicated ammonia refrigeration plant through the 230 concrete blocks that make up the structure. Without this active cooling system in place, all that concrete would still be setting today!



Diverting the Colorado River

Constructing the Hoover Dam would have been impossible with the Colorado River still flowing through Black Canyon. So, the builder endeavoured to divert the course of the river. Four tunnels with a combined length of over five kilometres (three miles) were dug into the canyon walls and around the dam site. The river was diverted into these tunnels by blocking its natural course with rubble as well as detonating a hole in a cofferdam – a temporary enclosure that stopped the river draining into the diversion tunnels. This was only performed for the two tunnels on the Arizona side of the canyon. The two drainage tunnels on the Nevada side were held in reserve for the higher waters in spring and summer.

Hoover Dam structure

How It Works explores one of the world's greatest engineering feats

Lake Mead
At maximum capacity, the lake on the upstream side of the dam can yield 219,700kg/m² (45,000lb/ft²) of force at its base.



Spillway inlet
Overflow from Lake Mead drains downstream via these inlets. They've been used only twice since the dam was built.

"The Hoover Dam was the largest in the world requiring over 3.3 million cubic metres of concrete to build"

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Highway
For many years the top of the Hoover Dam served as a public highway between Nevada and Arizona until the Hoover Dam Bypass was opened in 2010.

Elevator
An elevator takes tourists down a 152m (500ft) shaft to the base of the dam to the power plant.

Intake towers
Water drains into these towers to supply the power station.

Penstocks
The pipes that deliver water to the power plant are known as penstocks. The water in these pipes is under high pressure from the lake behind the dam.

Power house
Originally rated at a 1.344GW capacity, the dam's current installed power capacity is 2.078GW.

Learn more

Go to **www.howitworksdaily.com** for some fascinating facts on megastructures, a look at five of the most impressive structures built on Earth by humankind, including: the Great Wall of China, the Mirny Mine in Russia and the Three Gorges Dam, China.

Generating power

The Hoover Dam's hydroelectric power plant is located on the downstream side at the bottom of the dam. Excavating the area for the station was finished in 1933, after the dam itself. Concrete began to be poured for the plant at the end of the same year and continued for the next two years, even overlapping with the filling of Lake Mead behind the dam in 1935. With war brewing in Europe and the vulnerability of the plant considered, 1.1 metres (3.6 feet) of concrete, rock and steel topped with tar formed a robust ceiling. Three Francis turbine generators were installed in 1937 when the power plant went on line, with 14 more added over the decades. Its average power generation in nearly 80 years has been around four terawatt-hours, helping to fulfil the huge power requirements of Las Vegas among other west coast communities.

The statistics...

Hoover Dam

Height: 221m (726ft)

Crest: 379m (1,244ft)

Weight: 6.6 million tons

Max upstream depth: 180m (589ft)

Max water pressure: 219,700kg/m² (45,000lb/ft²)

Total material excavated: 4.2 million m³ (148.5 million ft³)

Average annual power: 4 billion kWh

© Thinkstock

DID YOU KNOW? *The Hoover Dam was initially called Boulder Dam, as Boulder Canyon was the original site location*

KEY DATES HOOVER DAM

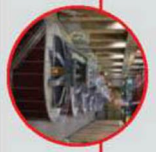
1928 A dam in Black Canyon is authorised by Congress and Six Companies wins the contract.

1935 President Roosevelt (right) formally opens the dam on 30 September to a crowd of 10,000.



1947 The 'Boulder Dam' name is removed and the House of Congress bestows the name 'Hoover Dam' instead.

1961 The last of the 17 turbines is installed into the power station, bringing it up to full capacity.



1983 The 1983 floods see the Hoover Dam use its spillways for only the second time (the first being a 1941 test).

How pacemakers work

Learn how these cutting-edge devices are giving tired hearts a new lease of life

The heart has a natural pacemaker called the sinoatrial node. This fires electrical impulses which regulate our heartbeat. Certain conditions cause this natural pacemaker to malfunction though, which is where artificial pacemakers come into play.

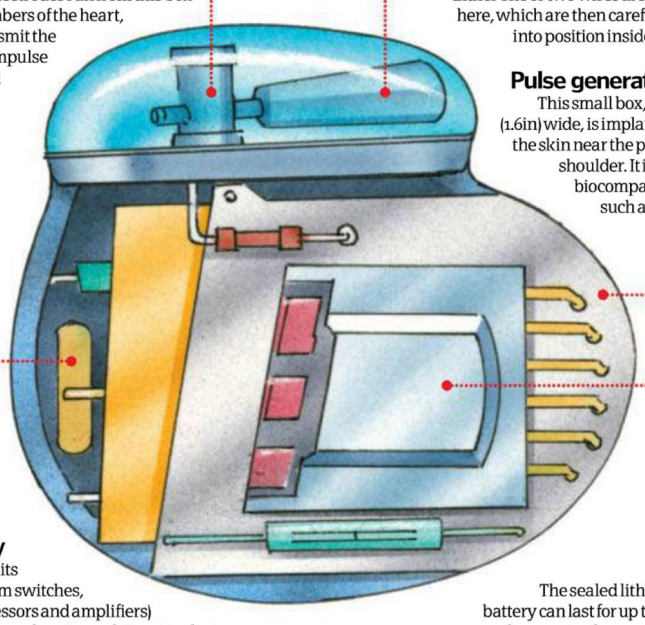
There are several different types of artificial pacemaker, each suited to certain conditions. For those with irregular or very slow heartbeats, a permanent pacing device will send out an impulse to control every single beat. For those who have occasional problems, meanwhile, a responsive pacemaker will take over only when it detects irregular cardiac rhythms.

The power supply for artificial pacemakers needs to be long-lasting and reliable. The most commonly used type is a lithium battery, which has been proven to last for ten years. At that stage they won't suddenly cut out, as specialist equipment can detect those low on power in plenty of time. They can then be swapped out for a new one in a second minor procedure.

Pacemaker aftercare

A pacemaker is implanted as a day-case procedure under a local anaesthetic. The pacemaker box is put just beneath the skin in the upper left-hand corner of the chest.

The main environments people with pacemakers should avoid are those with strong magnets, which can affect the pacing capability and also the position of the machine. This means steering clear of MRI scanners and certain electric motors, which generate electromagnetic fields. Microwaves and airport security gates are perfectly safe, and certain modern pacemakers are even designed to be MRI compatible too.



Electrode connector box
Fine wire electrodes run from this box to the chambers of the heart, which transmit the electrical impulse that control its rate.

Electrodes
Either one or two wires are connected here, which are then carefully placed into position inside the heart.

Pulse generator case
This small box, about 4cm (1.6in) wide, is implanted under the skin near the patient's left shoulder. It is made of a biocompatible metal such as titanium.

Circuitry
These circuits (formed from switches, microprocessors and amplifiers) generate the pulse at a predetermined rate, or can also fire the pacemaker on an 'as-needed' basis.

Battery
The sealed lithium iodine battery can last for up to a decade, and generates the energy for each paced impulse sent to the organ.

© Thinkstock; Prof Marko Turina

How can waterjet cutters slice through steel?

The amazing tech that enables water to accurately cut both soft and hard materials

Waterjet cutting can be used to slice through most materials and is a process that does not give off hazardous vapours or waste.

Intensifier or direct drive pumps get the water to the high pressure needed for cutting. The more powerful intensifier pump uses hydraulic oil pressurised at 211 kilograms per square centimetre (3,000 pounds per square inch) to drive a piston biscuit/plunger. This pushes a flow of filtered water that is intensified by 20 times to 4,218 kilograms per square centimetre (60,000 pounds per square inch).

Pure waterjets are used to cut card, nappies and soft materials. The velocity of the water from the jet, rather than the water pressure itself, erodes the microscopic grains of the material using this technique. It cuts material without affecting its inherent structure.

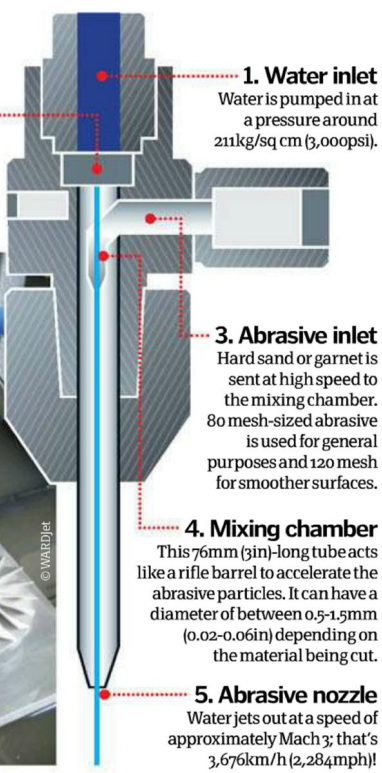
Abrasive waterjets, on the other hand, incorporate a rough substance like sand that is accelerated by the water to erode the material, which can include metal, stone or ceramics.

The simplest variety of waterjet machine tools are stationary and cut the material fed into them much like a bandsaw. The more complex programmable five-axis machines, meanwhile, can cut composite materials in three dimensions.



Turning the power of high-pressure water into an industrial tool

© WARDJet



1. Water inlet
Water is pumped in at a pressure around 211kg/sq cm (3,000psi).

2. Orifice
Consists of a sapphire, ruby or diamond with a 0.1-2.5mm (0.004-0.1in)-diameter hole in it, which drastically increases the pressure of the water.

3. Abrasive inlet
Hard sand or garnet is sent at high speed to the mixing chamber. 80 mesh-sized abrasive is used for general purposes and 120 mesh for smoother surfaces.

4. Mixing chamber
This 76mm (3in)-long tube acts like a rifle barrel to accelerate the abrasive particles. It can have a diameter of between 0.5-1.5mm (0.02-0.06in) depending on the material being cut.

5. Abrasive nozzle
Water jets out at a speed of approximately Mach 3; that's 3,676km/h (2,284mph)!

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DID YOU KNOW? *The world record for most chainsaw juggling catches is held by Ian Stewart, who achieved 94 tosses*

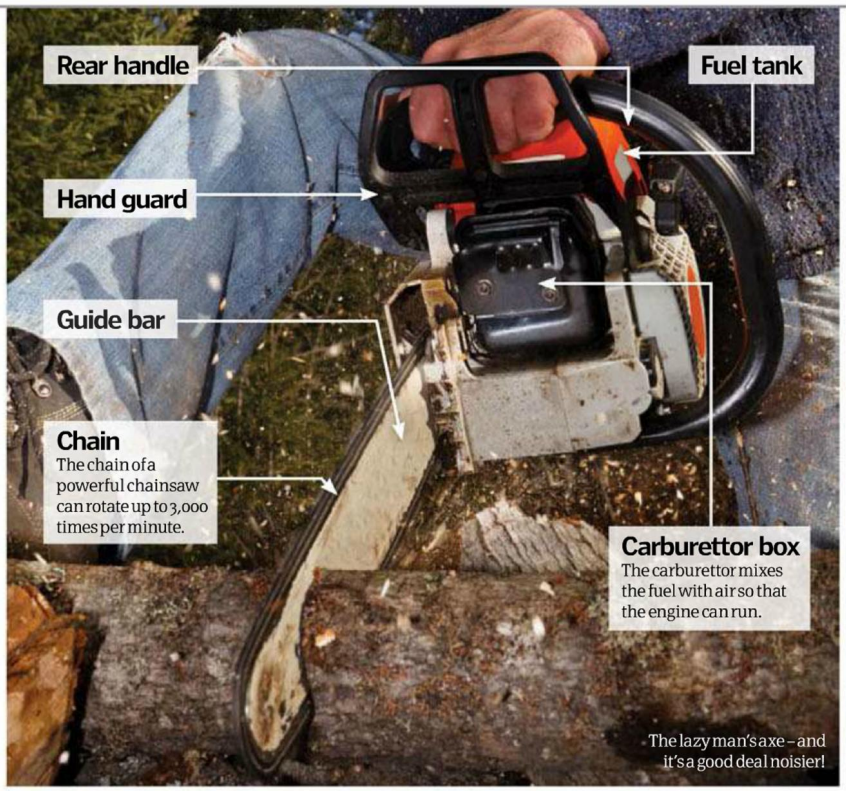
Chainsaws explained

How do these powerful cutting machines work?

When it comes to clearing trees there's no better tool than the chainsaw. In general, chainsaws employ a one-cylinder petrol engine in tandem with a saw blade to provide intense cutting power. The chain operates like that on a bicycle, except that it spins around a guide bar and plays host to around 50 razor-sharp steel teeth!

Most chainsaws hold about 0.5 litres (one pint) of petrol in their fuel tanks, which is fed through a carburettor to mix with air. A two-stroke engine uses a spark plug to ignite this air-fuel mixture. This in turn moves a piston back and forth, which is then converted into rotary motion by a rod and crank.

A driveshaft transfers this motion to a clutch, which feeds the chain around the guide bar to provide the cutting power of these machines. The clutch of the chainsaw uses a safety mechanism to ensure the chain only rotates when the throttle is pulled by the operator even if the engine is running idle. Chainsaws have a variety of uses but are predominantly utilised in deforestation and the clearing of debris after a storm.



The lazy man's axe – and it's a good deal noisier!

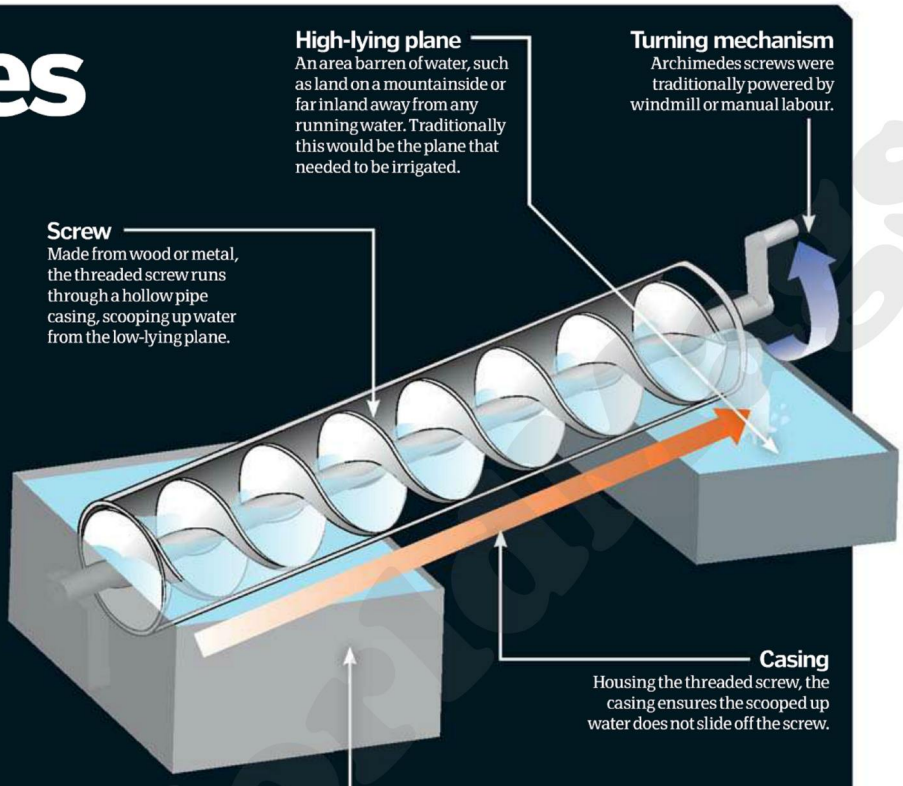
Archimedes screw

An ingenious ancient method of transferring water from one plane to another

Attributed to inventor and polymath Archimedes in the 3rd Century BC, the Archimedes screw works by utilising the angular frequency and speed of a rotating thread to transfer water from a low-lying plane to a higher one.

The machine consists of a hollow pipe angled at 45 degrees with a threaded screw encased within, which rotates once wound. The bottom of the cylinder is submerged in the water on the lower plane while the top end empties out into a channel or basin. As the screw rotates, the screw scoops up water at the bottom and, as it is encased within the cylinder, is forced to slowly slide up the thread to the top and onto the higher plane. In addition, any water lost through the small gaps between the screw and the cylinder are recollected by the thread directly below the one that lost it, ensuring mechanical equilibrium while in operation.

Traditionally Archimedes screws were used for irrigation, allowing water to be artificially transported to ditches, and were operated by hand. Modern variants are now primarily used for drainage.



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"Before transactions are completed, the machine's computational software deducts a processing fee"

Inside coin counters

The science of sorting and technology of tabulation explained

Currency-counting machines – such as those proliferated by US company Coinstar – work in a two-stage process, firstly separating coins by type and secondly tabulating the partial or total coinage.

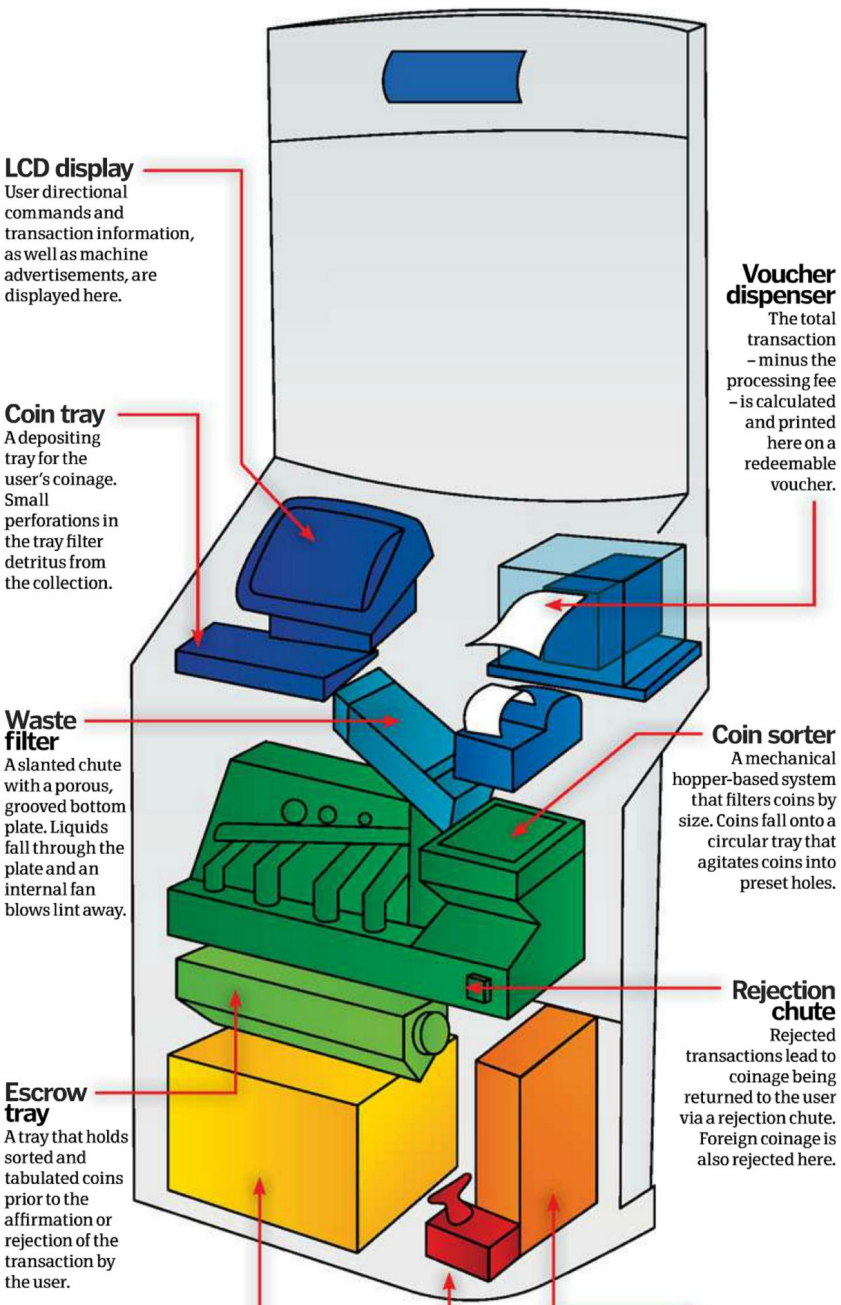
Individual coin types are separated by a hopper-based filtering system, which usually involves coins being deposited onto a circular tray via a top-mounted chute, and then mechanically agitated into preset coin slots via the force of gravity. At this stage the hopper mechanism also filters out illegal or non-coinage, rejecting it via a front-mounted return chute. As the legal coins are filtered from the tray, they drop through individual funnels into a holding container, where they are mechanically weighed.

The overall weight of an individual stack of coins is then assessed by a central computer system. This has preset weight-to-value ratios logged within its tabulation software that – after the coins have been mechanical weighed and converted into a binary format – it can draw upon to calculate the coins' total value. This method of calculation, when combined with all other stacks of coin types, allows the total value of inserted coins to be determined. This information is then presented to the user via a front-mounted LCD display.

Before transactions are completed, however – affirmed by the user manually – the machine's computational software deducts a processing fee from the total coinage tabulated if the user wishes to collect/transfer the funds. This is usually around ten per cent of the total value of the inserted coins. Once completed, the coin counter generates a redeemable voucher from a front-mounted printer, which can then be cashed by store staff.



© Coinstar



LCD display
User directional commands and transaction information, as well as machine advertisements, are displayed here.

Coin tray
A depositing tray for the user's coinage. Small perforations in the tray filter detritus from the collection.

Waste filter
A slanted chute with a porous, grooved bottom plate. Liquids fall through the plate and an internal fan blows lint away.

Escrow tray
A tray that holds sorted and tabulated coins prior to the affirmation or rejection of the transaction by the user.

Storage container
Affirmed transactions are deposited from the escrow tray into a storage container ready for removal by staff.

Maintenance printer
A secondary printer utilised by operating staff to receive statistical/operational read-outs from the machine.

Computer system
Currency calculation, processing fees and the operating software are controlled from a computer system.

Rejection chute
Rejected transactions lead to coinage being returned to the user via a rejection chute. Foreign coinage is also rejected here.

Coin sorter
A mechanical hopper-based system that filters coins by size. Coins fall onto a circular tray that agitates coins into preset holes.

Voucher dispenser
The total transaction – minus the processing fee – is calculated and printed here on a redeemable voucher.

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5 TOP FACTS TORPEDO TRIVIA

Variety
1 Modern torpedoes are divided into a wide variety of classes and types. These include lightweight, heavyweight, straight-running, autonomous homing and wire-guided.

Nautilus
2 The first recorded use of a torpedo is 1800, when American inventor Robert Fulton launched a primitive, floating explosive charge from his Nautilus submarine.

Tesla
3 While unconfirmed, it's reported that Nikola Tesla invented a remote-controlled, radio-guided torpedo in 1897. He patented the technology and showed it to the US military.

Launchers
4 Torpedoes are commonly launched by submarines, however they are also carried by attack helicopters and jets, as well as fired from warships via specialised launch tubes.

Warhead
5 Modern torpedo warheads are typically filled with polymer-bonded explosives (PBX). These are used as the explosive pulse they produce is particularly intense and destructive.

DID YOU KNOW? *The Sting Ray, one of the two torpedoes now used by the British Royal Navy, entered service in 1983*



How torpedoes work

What enables these marine missiles to pack such an explosive punch?

This US Navy torpedo launcher is being tested during training exercises

A torpedo is a self-propelled missile used to engage targets underwater, exploding upon contact with a vessel's hull.

Torpedoes are classified depending on their launch mechanism, warhead composition and manner of propulsion. Launch platforms can include: submarine missile tubes – where the torpedo is directly fired from a torpedo bay underwater; ship-mounted, gas-powered cannon arrays; and via trajectory-planned freefall from helicopter gunships.

Torpedo warheads are commonly constructed from an aluminised explosive, such as Torpex or PBX. The aluminium centre is used as it helps generate a sustained explosive pulse, which is particularly destructive against armoured, underwater targets. Further, the actual warhead is usually shaped (normally conically) in order to maximise hull penetration. This leads to far greater internal damage to the unfortunate target, potentially critically breaching and flooding the vessel.

Propulsion and guidance are handled by systems within the actual torpedo. Propulsion is usually delivered by an electric battery stack in partnership with a hydraulic/mechanical actuation system. This modern tech enables torpedoes to be stored for lengthy periods of time without losing power efficiency and drive speed. Guidance is handled by an array of gyroscopic sensors along with a central navigation data system. This is fed information by both the launcher and also via active or passive acoustics – the former working by the torpedo generating sound signals which echo off their target like sonar, and the latter working by directly homing in on the target's noise profile.

Currently, the Royal Navy uses two main torpedoes, the Spearfish and Sting Ray, while the US Navy fields five of varying types and weights.

Inside a Sting Ray Mod 1 torpedo



Warhead
A new insensitive munition-shaped charge warhead ensures a large isotropic blast resulting in great damage to the target.

Navigation
A solid-state inertial measurement unit is used to support complex tactical software modes to evade modern countermeasures.

Power
A magnesium/silver chloride battery stack provides power for on-board electronic systems, as well as delivering a longer range and greater reliability.

Electronics
A digital signal processor enables improved target classification and a next-generation autopilot allows execution of complex tactical software routines.

Propulsion
An electro-mechanical actuation system generates forward momentum. The absence of pumps and fluids reduces maintenance requirements.

Handcuffs explained

A common device in the law-enforcer's kit, how do these restraints work?

There are three main varieties of handcuff: a rigid type that comprises a metal bar between the cuffs; hinged handcuffs; and the more common chained handcuffs.

With an open end of the cuff, the bracelet is placed around the wrist and closed, pivoting the ratchet around so the teeth engage with the teeth of a pawl that secures them together. The locking mechanism prevents the cuff from being opened in one direction, while the wrist stops the bracelet from sliding open in the opposite direction. The only way to undo the bracelet is to disengage the teeth, by opening the lock with a key. Handcuffs tend to be made of strong steel with nickel plating.



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"Designed to withstand enough weight that it doesn't reach that all-important elastic limit"

Bungee cords

How a bungee rope provides resistance to impacts



Inside a bungee cord – which is often known as a shock cord – are several strands of rubber. This rubber provides the elasticity that absorbs the shock of an impact or a sudden force, which would otherwise injure a human. Elasticity refers to the cord's ability to return to its original shape after an outside force is applied and then removed. Conversely, the elastic limit is the maximum amount of force that can be applied to the cord before it becomes unable to return to its original shape. A bungee cord, however, is specially designed to withstand enough weight that it doesn't reach that all-important elastic limit. Instead, the rubber allows the cord to gradually stretch providing impact resistance. A bungee cord is similar in application to an elastic band except that is has a much higher density and flexibility to prevent it from deforming or snapping.

The outer layer of the bungee cord is constructed of woven polyester fibre that wraps around the elastic rubber inside. By using a cross-hatched weave, the fibre can remain durable but slightly separable during freefall. This means the interlocked fibres can expand slightly as the bungee jumper exerts a downwards force, adding strength and flexibility to the cord while still protecting and holding the rubber underneath.

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Chinese bronze-casting furnaces

The innovation that led to some of the finest bronze work ever produced

Neolithic people were familiar with copper, but the mineral was rare and tricky to work with. The discovery that copper could be combined with tin to make a stronger and more easily manipulated material heralded a whole new era: the Bronze age.

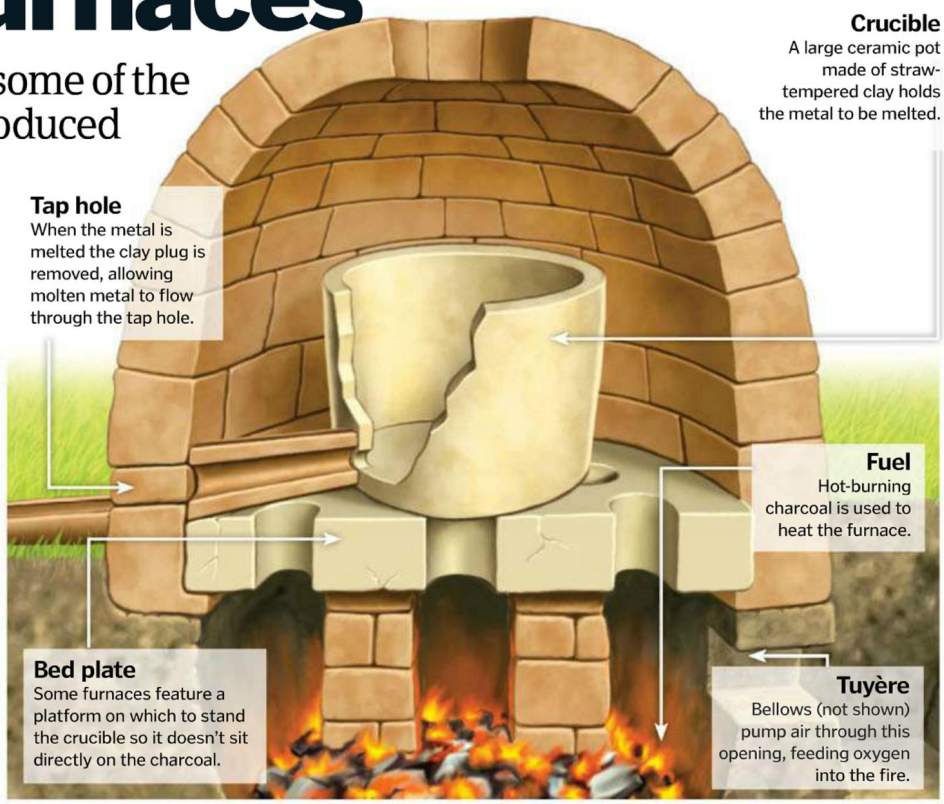
In early furnaces, a large ceramic pot held the molten metal over a coal fire and air from a pair of bellows was pumped in via an opening. As the bronze melted, it sank to the bottom of the vessel while impurities collected on top. A ramrod was used to break and dislodge a clay plug blocking the spigot, allowing metal to pour out of the crucible into waiting moulds.

Once the metal cooled, the moulds were broken and the seam marks and flashing removed. These moulds were made in sections, so the completed bronze might be assembled from multiple individually cast elements.

Early bronzes resembled forms previously made from clay. However, as casting technology and familiarity with the new medium improved, bronze work became more complex and included everything from intricately decorated ceremonial pots to weaponry.

Inside the furnace

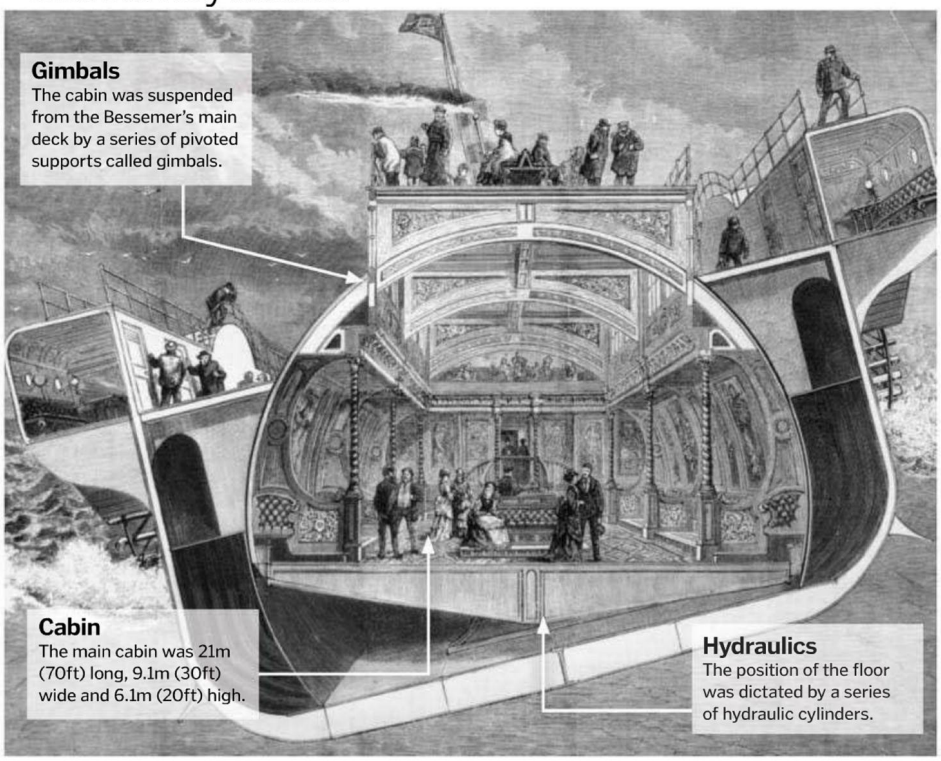
Versions of this are still used to this day



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Why swinging saloons failed

The SS Bessemer was a revolutionary new design of vessel that infamously didn't work – find out why it failed

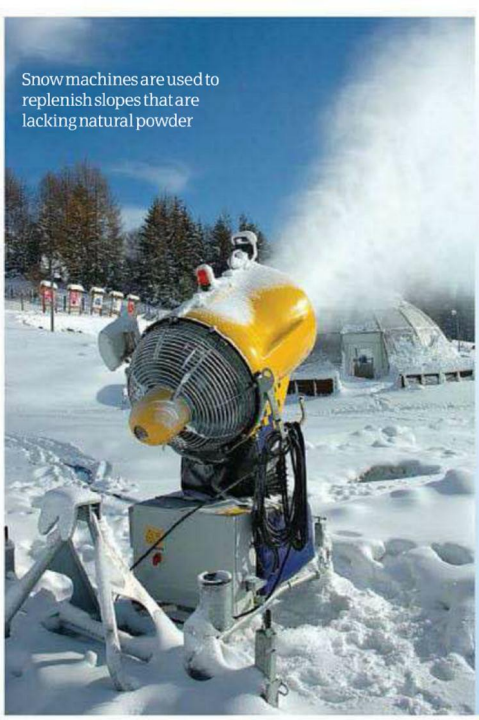


The SS Bessemer was an experimental Victorian ship that attempted to solve the age-old problem of seasickness among passengers by isolating the main cabin (saloon) from the rest of the vessel. The idea behind this was that if the main saloon could remain stationary (horizontal) in relation to the tilting hull of the ship, then passengers would not be exposed to stomach-churning, unnatural movements while on board.

The cabin was isolated by suspending it on gimbals from the deck and kept horizontal mechanically by an array of hydraulic cylinders controlled by a steersman. To keep the cabin floor at 180 degrees, the steersman simply consulted a spirit level to determine the tilt and then counteracted it. On paper it seemed like an ingenious solution; in reality, however, it was to prove a monumental failure.

While the suspension system worked, mitigating a large amount of cabin sway, the shifting centre of gravity made the ship almost unsteerable and very unpredictable while at sea – two factors that led it to crash into Calais pier on its first trip.

The poor performance at sea, catastrophic maiden voyage and huge costs involved in the project saw it being wound up, with the ship dismantled only four years after its first – and last – commercial voyage.

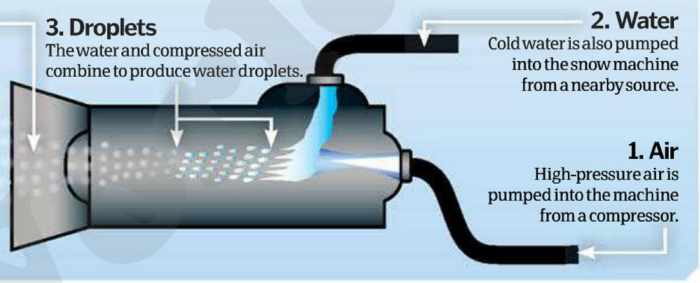

Snow machines are used to replenish slopes that are lacking natural powder

Snow machines

How do these devices produce manmade snow?

Snow machines are used on both indoor and outdoor ski slopes around the world to provide additional snow when the real stuff is lacking. The material they create is actually snow, but the process by which it is made is a little different to the natural system. Snow that forms as nature intended in clouds is basically frozen crystals of water, and the same is true of snow guns.

However, these devices have to create a cold environment in which they can produce snow, simulating the conditions in clouds. Most snow cannons do this in a relatively simple process, combining cold water and compressed air to produce water droplets. The guns are connected to a supply of water and high-pressure air, which are both pumped into the machine. The droplets then freeze into ice crystals inside the machine and, when fired out by a fan, fall as snow. Most machines lack the ability to change their firing direction (like a sprinkler), so ploughs and other vehicles are used to spread the fresh powder across the slopes.



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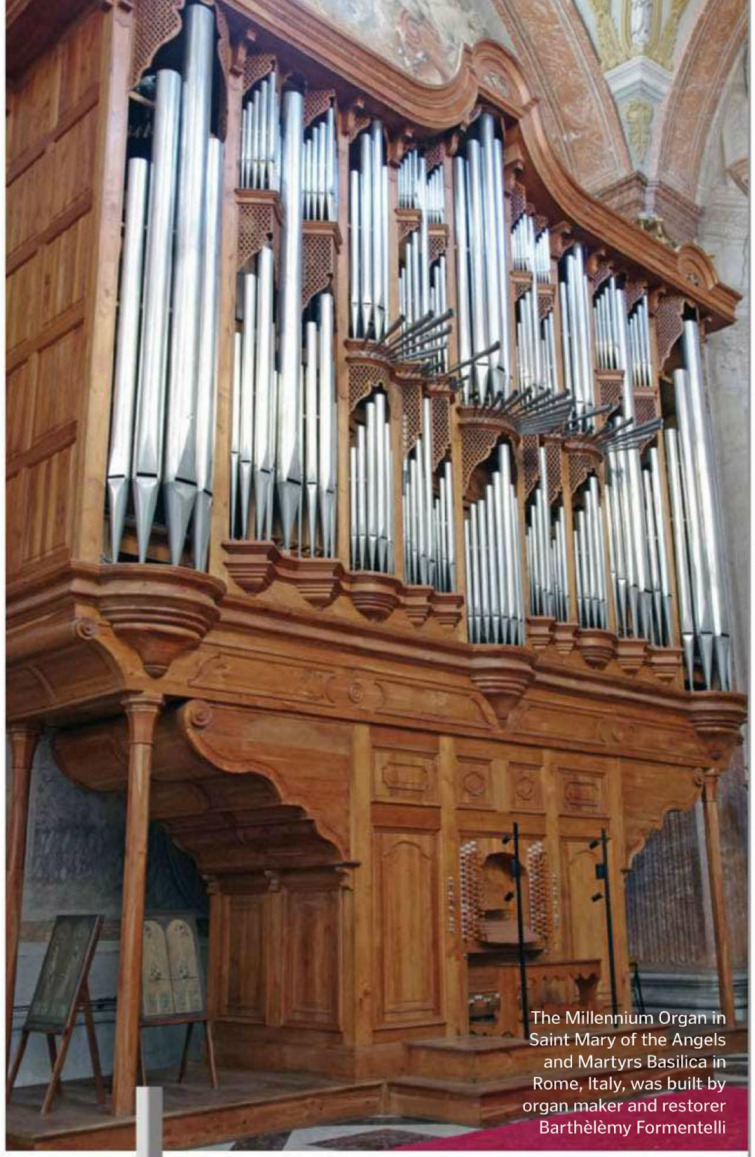
How do pipe organs work?

Explore the inner workings of one of the largest and most complex musical instruments on the planet, and see how it produces such a distinctive sound

The pipe organ is most commonly encountered in churches and concert halls, where they are used for the performance of sacred and secular music. Its origins can be traced back to Ancient Greece in the 3rd century BCE, but it wasn't until the 12th century CE that organs began to evolve into a complex instrument capable of producing different timbres. The world's oldest playable pipe organ is located in the Basilica of Valère in Sion, Switzerland, and was built around 1430.

An organ produces sound by driving pressurised air (wind) through a series of pipes selected via a keyboard. As each pipe produces a single pitch, multiple pipes are required in sets (called ranks), each of which has a common timbre and volume. Most organs have many ranks of pipes of differing timbre, pitch and loudness that the organist can play in combination through the use of stops.

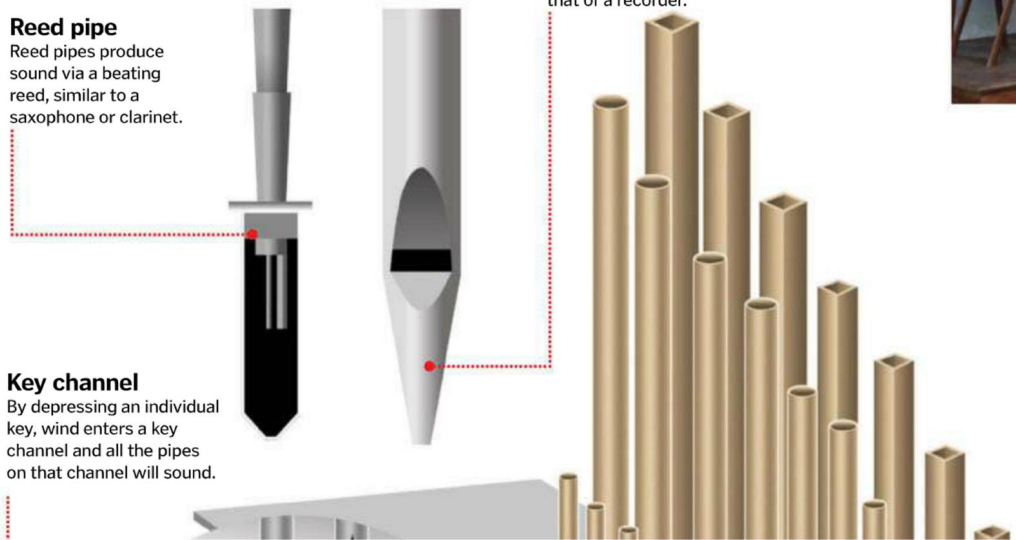
A pipe organ typically has two or more keyboards – manuals – played by the hands, and a pedal board played by the feet. The organ's continuous supply of wind produced by an electric blower enables it to sustain notes for as long as the corresponding keys are pressed. This is unlike a piano whose sound begins to fade immediately after the key is struck. The smallest portable pipe organs may have only one or two dozen pipes and a single manual, whereas the largest stationary organs may have over 30,000 pipes and seven manuals.



The Millennium Organ in Saint Mary of the Angels and Martyrs Basilica in Rome, Italy, was built by organ maker and restorer Barthèlèmy Formentelli

Internal organs

Despite widely varying in size, all pipe organs work around the same basic principles...



"A pipe organ typically has two or more keyboards – manuals – and a pedal board played by the feet"

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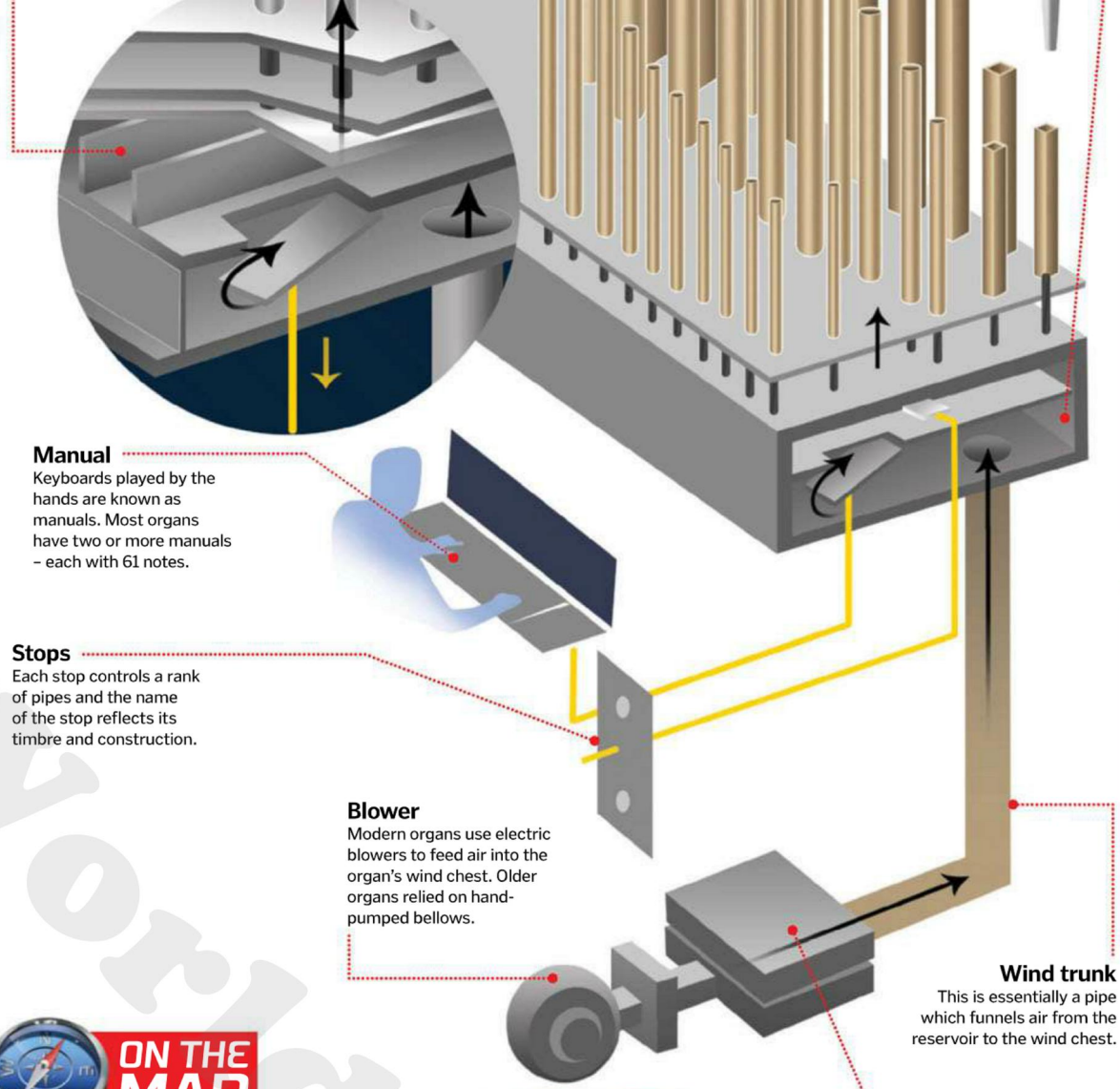
33,114

BIGGEST PIPE ORGAN

The Boardwalk Hall organ in New Jersey, USA, is not only the loudest in the world, producing 130 decibels at a one-metre (3.3-foot) distance, but also has the most pipes (over 33,000)!

DID YOU KNOW?

Pipe organs have been made out of many novel materials including bamboo, marble and even porcelain!



Manual
Keyboards played by the hands are known as manuals. Most organs have two or more manuals – each with 61 notes.

Stops
Each stop controls a rank of pipes and the name of the stop reflects its timbre and construction.

Blower
Modern organs use electric blowers to feed air into the organ's wind chest. Older organs relied on hand-pumped bellows.

Wind trunk
This is essentially a pipe which funnels air from the reservoir to the wind chest.

Reservoir
The electronic blower pumps air into the reservoir where it is pooled until required.

How does wind generate sound?

Sound is produced in a musical instrument, such as a clarinet or trumpet, by the movement of an enclosed column of air blowing through a reed; others require buzzing into a metal mouthpiece. Sounds are vibrations which are transmitted through the air as waves to be received by our ears. The frequency of a sound is given by the number of vibrations per second, measured in hertz. Humans can perceive only sounds with a frequency in the range of 0.02-20 kilohertz.

Most musical instruments produce sounds with frequencies of 27.5-4,186 hertz. If air for the energy waves to travel through is absent, such as in outer space, no sound is possible. When vibrations are fast, the ear will hear higher-pitched sounds; in comparison, slower sound waves create lower pitches.

An organ played by the sea...

The sea organ is a 70-metre (230-foot)-long architectural work-cum-experimental musical instrument located on the seafront of Zadar in Croatia. It is the world's first pipe organ 'played' by the sea. Stone steps on the quayside conceal 35 musically tuned polyethylene tubes and a resonating cavity, pierced by whistle openings on the steps. The movement of the sea pushes air through the tubes, into the cavity and out of the whistle openings and, depending on the size and velocity of the waves, different musical chords are produced. Seven successive groups of musical tubes are alternately tuned to two musically cognate chords of the diatonic major scale. The outcome of played tones and chords is a function of the random distribution of the wave energy to particular organ pipes. The waves thus create their very own 'music', a never-ending cycle of random harmonic sounds.



ON THE MAP

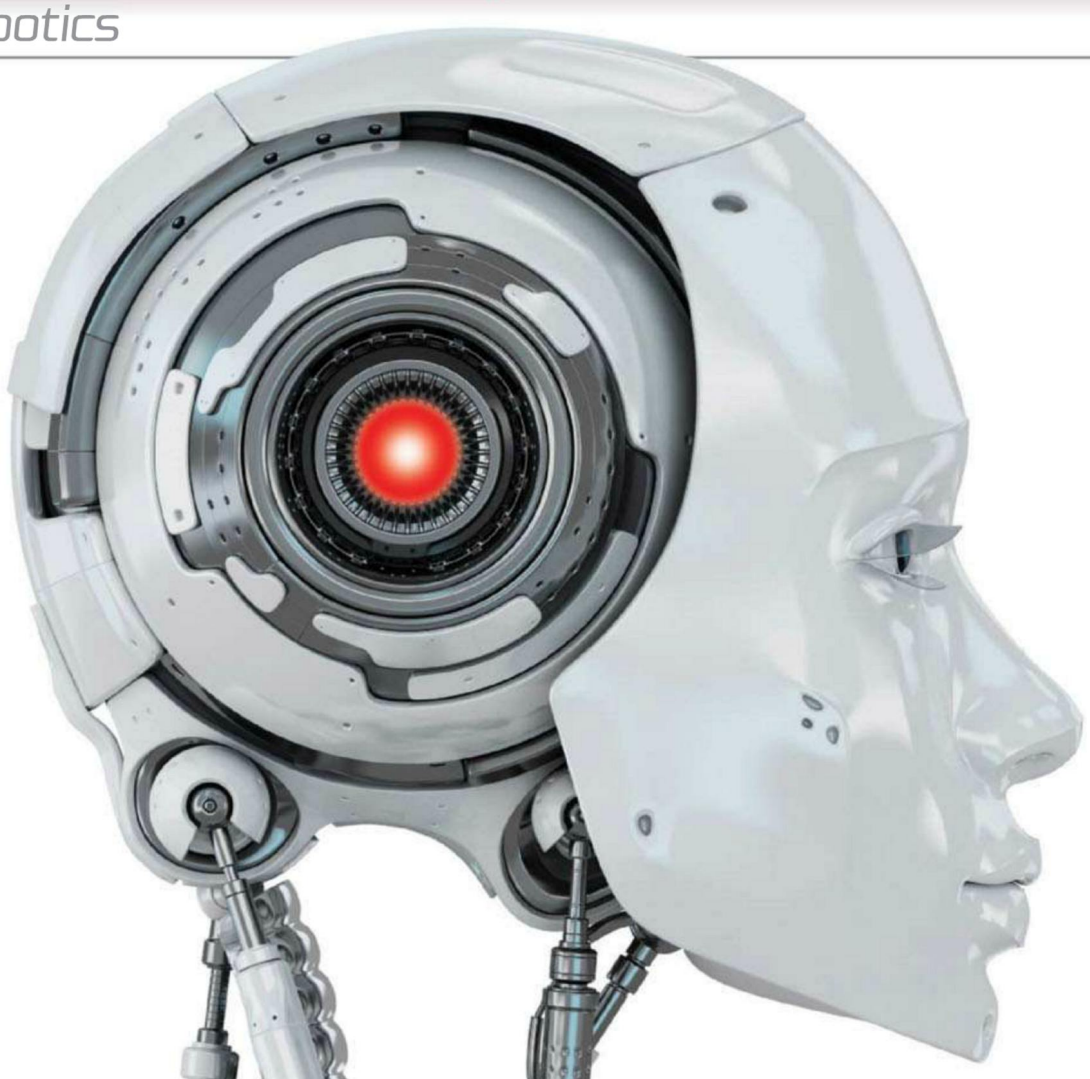


Giant pipe organs around the globe

1. Macy's Department Store, Philadelphia, USA
2. First Congregational Church, Los Angeles, USA
3. Milan Cathedral, Milan, Italy
4. Liverpool Cathedral, Liverpool, UK
5. Sydney Opera House, Sydney, Australia
6. National Concert Hall, Taipei, Taiwan

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"Improving strength and reducing weight are two vital requirements of any robotic system"



ROBOTS

DISCOVER HOW ROBOTICS IS TRANSFORMING OUR WORLD

Most people, at some point in their lives, have looked at one robot or another and exclaimed: "Wow!". Whether it's excitement, enthusiasm, fear or repulsion, there always seems to be some sort of emotional response to the appearance of the latest mechanical being.

Robotic technology has been steadily progressing over the last few decades, and new mechanics and materials are beginning to make it possible for robots to do some quite unbelievable things. Improving strength and reducing weight are two vital requirements of any robotic system as this allows ever-smaller robots to do bigger and better things. Materials such as carbon-fibre composites, advanced metal alloys, extraordinary plastics and modern ceramics make almost any physical requirement possible, but even newer technologies, such as carbon nanotubes, are promising almost unlimited strength.

The latest advances in brushless motor technology and control, lithium batteries and digital optics open up possibilities that simply have never existed before. These technologies are still quite recent, however, so they have a long process of refinement ahead of them.

Robots are being designed specifically to work with disabled and vulnerable children and adults, following observations that patients responded extraordinarily well to friendly, non-threatening robots, often when human contact had failed. This is amazing as having such emotional

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5 TOP FACTS
ROBOT TRIVIA

Emotionally attached
1 Research suggests two-thirds of people who own Roomba robot vacuum cleaners have named their machine and some even clean up first before switching them on!

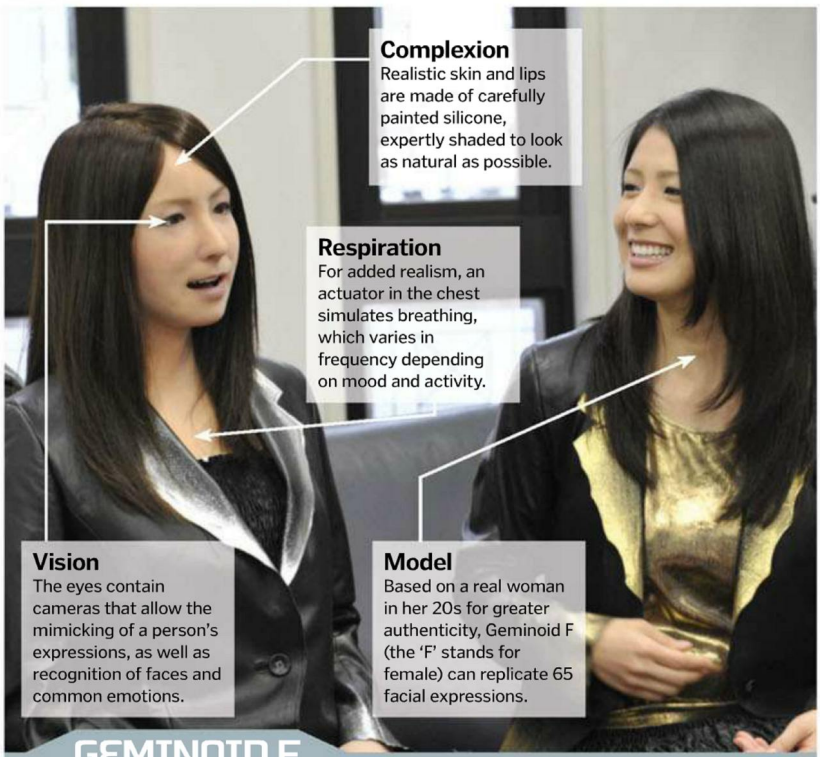
Elektro
2 At the 1939 New York World's Fair the Westinghouse Electric Corporation exhibited Elektro, a humanoid robot that could walk about, speak 700 words and had a pet robo-dog.

Robotic roots
3 In 1495 Leonardo da Vinci conceived a humanoid robot, reminiscent of a knight in armour, with moving parts. A functional version has since been manufactured by NASA.

Armed and ready
4 NASA employs a large range of robotic equipment. Robot arms, such as the ISS's Canadarm2, are used to lift, manoeuvre and recover large objects in space, eg satellites.

What's in a name?
5 The word robot comes from the Czech 'robota', which translates as work, or forced labour. It was first used in Karel Capek's 1920 play *RUR (Rossum's Universal Robots)*.

DID YOU KNOW? *ASIMO is 120cm (47.2in) tall, which allows him to reach light switches and operate in a human workspace*



GEMINOID F
The human impersonator

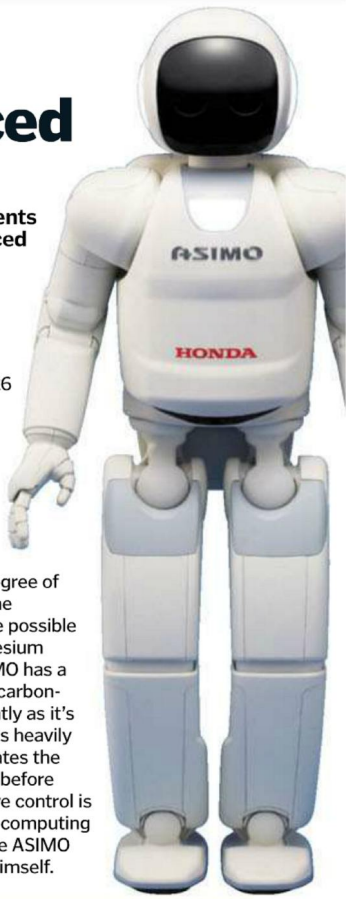
Meet perhaps the most human-looking machine ever to have been built

✓ A convincing human ✓ Pop singer replacement ✗ Passes the Turing Test

Underneath the realistic silicone skin of the Geminoid F lies the familiar face of a robot. Machined from aluminium, the latest version of this Japanese robot has just one quarter of the hardware used in its predecessor (Geminoid HI-1), with just 12 degrees of freedom. Unlike most modern robots, the Geminoid series doesn't use electric motors for animation. Compressed air and pneumatic rams are used instead, as the creators feel it gives a more human-like quality to their movements. Geminoid F uses an electric air compressor to supply her many actuators. These are controlled by computer-operated valves, in order to reliably synchronise the 65 facial expressions to match the words spoken by the robot. Human head movements, gestures and facial features are observed, recorded by the computer and mimicked to improve realism. Operators can speak via the Geminoid, or have her respond autonomously using a computer program to work out a suitable reply to questions.

ASIMO
The advanced humanoid

We reveal the latest enhancements to Honda's ever-popular Advanced Step in Innovative Mobility

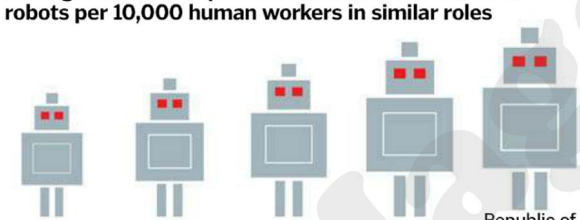


✓ Uses sign language
✓ Serves you Martinis
✓ Plays football

ASIMO has been in development for 26 years. He can now run, jump, climb stairs, make drinks and shake hands, so his physical development is going well. The key to future progress is to take advantage of new tech such as ever-faster processors and the much-anticipated quantum computers. ASIMO uses brushless servomotors that allow a very high degree of motion accuracy. Miniaturisation of the gearboxes and motors has been made possible by advanced materials such as magnesium alloys and neodymium magnets. ASIMO has a magnesium skeleton, but a switch to carbon-fibre composites will benefit him greatly as it's both lighter and stronger. ASIMO relies heavily on a predictive algorithm that anticipates the most likely requirements of the limbs before moving them. This type of pre-emptive control is an exciting area as it's only limited by computing capability, so it may not be long before ASIMO can not only move but also think for himself.

Robot density

The figures below represent the number of industrial robots per 10,000 human workers in similar roles



bonds with inanimate objects is counterintuitive: what is it about robots that makes them lovable or trustworthy? Extensive research is now underway into therapeutic robotic applications.

What really makes modern robots special, though, is the key element in any automaton: the 'brain'. This has been growing year after year, with computers getting ever-faster and more capable. Modern laptops are powerful enough to run some of the most complex robotic systems, which has made the whole industry accessible to innovators that stimulate new ideas. We are, however, approaching a key point in history, when computers can't get any faster without a fundamental change in the way they work, and quantum computing will either happen, or it won't. This will be an evolutionary crossroads for robots. They will either get exponentially smarter almost overnight – maybe to the point of being self-aware – or their meteoric rise will suddenly level off and they will remain at their current level, more or less, for the foreseeable future.

It's an exciting time for those interested in these complex machines, as they're so advanced, they surely can't develop at this rate for much longer. The question is, when current materials can get no stronger, and conventional computers can get no faster, will robot development step up to a whole new level, or will it hit a brick wall? Only time will tell.

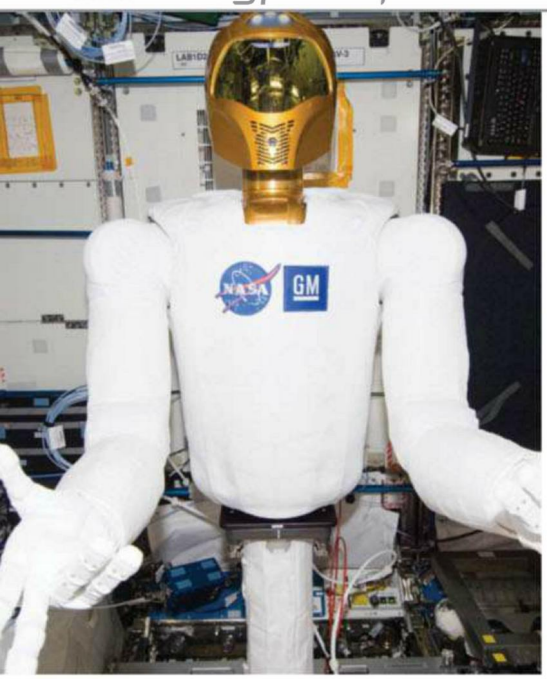
Do Asimov's laws still apply?

Sci-fi author Isaac Asimov wrote the 'Three Laws of Robotics' in 1942 to govern the direction of his fiction. The first law stated that a robot may not harm a human or allow them to come to harm through inaction. The second was that a robot must obey humans except where the command would violate the first law, and the third was that a robot must protect its existence except where this violates laws one and two. Though these guidelines have achieved a cult-like status, robot ethics have evolved as much as the tech.

© Getty; Honda

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"Robonaut is leading the way for future robotic systems to work alongside humans in space"



ROBONAUT 2

The astrobot

The first humanoid robot in space has been lending a helping hand to astronauts on the ISS

- ✓ Goes where astronauts daren't
- ✓ Steady arm
- ✗ Can go for a stroll

The latest version of the Robonaut is an engineering marvel. Not only does he look cool, but he's also leading the way for future robotic systems to work alongside humans in space and industry. The International Space Station (ISS) supplies electricity to the super-advanced computerised control systems stored in Robonaut's torso, which in turn control brushless electric motors. The grease in the motors must be a special compound for fire resistance and to prevent 'out-gassing' in a vacuum. As advanced as he is, it's his personal interaction that's made his case for future development. Working alongside astronauts in the ISS has shown his inductive control system is powerful enough to move huge loads, yet gentle enough that accidental contact will cause no harm. This means that future industrial bots wouldn't need safety screens or emergency stop buttons.



E.ZIGREEN CLASSIC

The gardener

Dodging obstacles and trimming turf with the latest in auto-lawnmowers

- ✓ Cuts grass
- ✓ Avoids gnomes
- ✗ Takes cuttings to the dump

The E.zigreen Classic is a small, autonomous lawnmower that can adapt to its environment using sensors. It knows where the edges of the garden are thanks to limit wires, while ultrasound sensors detect obstacles. The cutting blades and the driving wheels are powered by electric motors and run off rechargeable batteries. A number of failsafe sensors ensure the mower deactivates if anything goes wrong, and it can return to its charging dock by itself.



iROBOT 710 WARRIOR

The warrior

This multifunctional robot is far from a one-trick pony with the ability to be fitted out for a host of scenarios

- ✓ Expert at mine excavation
- ✓ Arm-wrestling master
- ✗ Outlasts a fully charged iPhone

The 710 Warrior is a remote-control robot that can climb stairs and perform manoeuvres such as 'standing up' on its innovative tracks. The twin lithium batteries keep the powerful electric drive motors turning for up to ten hours at a time. It can be fitted with robotic arms, sensors or weapons, as well as cameras, data-links and a wireless internet hub to support the information and communication needs of troops and rescue workers. The amazing thing about this robot is that it can adapt to the ever-changing requirements of a mission with upgrades easily bolted on.



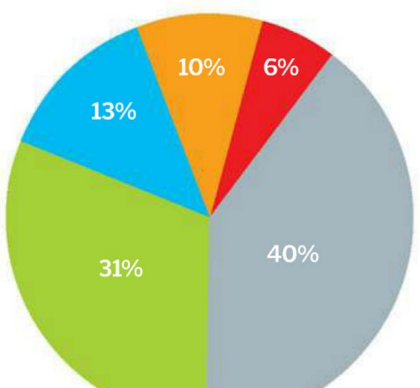
Strong arm
A two-link multipurpose arm can lift the weight of the robot.

More than tracks
The innovative tracked drive system makes this a very flexible platform.

Firm handshake
The powerful grippers can delicately lift items or crush them.

Service robot sales breakdown

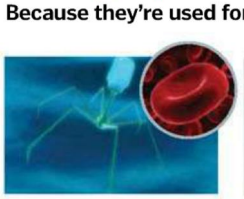
From agriculture to the military, which sector spent the most on service robots in 2011?



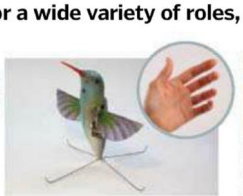
Key: Defence, Field, Logistics, Medical, Other
Source: International Federation of Robotics

Sizing up robots

Because they're used for a wide variety of roles, robots come in many different shapes and sizes...



Nanobot
As big as... A blood cell
These chemically powered tiny robots are being developed to locate and even treat cancerous cells.



© Thinkstock

Hummingbird
As big as... A human hand
The Nano Air Vehicle (NAV) has been created for military operations, such as covert surveillance.



© DARPA

HAL robot suit
As big as... A human leg
The Hybrid Assistive Limb (HAL) suit is a robotic exoskeleton designed for rehabilitation after injury.



© Prof Sankai/CYBERDYNE Inc

Curiosity rover
As big as... A small SUV
Currently the all-in-one lab is looking to establish whether life could ever have existed on Mars.



Titan
As big as... A lamppost
Articulated robot arms used in heavy industry are incredibly strong. KUKA's Titan can lift up to a ton!

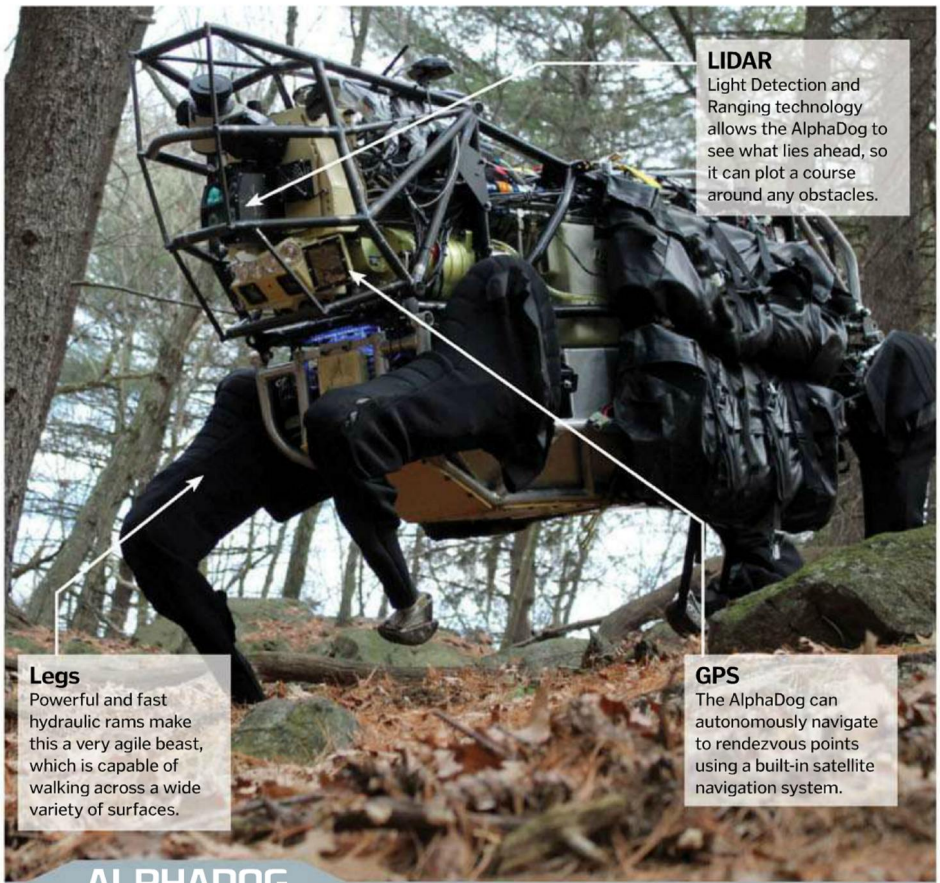
Robots

38

Percentage increase in sales of robots in 2011 from 2010

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DID YOU KNOW? *Robonaut has five 'eyes': two primary cameras, a pair of auxiliary cameras and an IR camera for gauging depth*



LIDAR
Light Detection and Ranging technology allows the AlphaDog to see what lies ahead, so it can plot a course around any obstacles.

Legs
Powerful and fast hydraulic rams make this a very agile beast, which is capable of walking across a wide variety of surfaces.

GPS
The AlphaDog can autonomously navigate to rendezvous points using a built-in satellite navigation system.

ALPHADOG

A soldier's best friend

Get to know the petrol-powered hydraulic pet that can traverse almost any terrain

✓ Faithful canine companion ✓ House-trained ✗ Can be kicked over

Very little captures the imagination more than a fully functioning robotic 'pack horse' that moves just like the real thing. This stunning machine has four legs that are independently controlled by a central computer, using the data from dozens of sensors. The data is continuously translated into navigation and stability requirements. The requirements are then translated into leg and hip movements by a powerful hydraulic system. The screaming petrol engine turns a high-pressure pump to push oil to 16 hydraulic servo actuators (four in each leg) through a network of filters, manifolds, accumulators and valves. This moves each leg quickly and precisely. The advanced stabilisation gyro and accelerometers keep the AlphaDog on its feet through mud, sand, snow and even ice. The technology and techniques developed on the AlphaDog have led to a two-legged version that moves just like a human, which opens up all number of possibilities for the future.



Sensors
There are a staggering 241 pressure sensors in each hand.

Sight
Stereo vision comes courtesy of two cameras in his head.

Friendly looks
To appear less threatening, the robot's features are heavily sculpted.

TWENDY-ONE

The butler

This workhorse is perfectly suited to caring for the infirm both in hospitals and the home

✓ Helps the aged
✓ Strong yet sensitive
✓ Can hold a pencil

Twendy-One is designed to offer assistance to the elderly and disabled. Using its innovative harmonic drive motor, Twendy-One is able to lift 35 kilograms (77 pounds). The highly dexterous hands and inductive passive control system ensure it doesn't impact a person or object hard enough to harm them. In order to manoeuvre around bends, Twendy-One rolls around on an omnidirectional wheel-based drive system. The torso also has 12 ultrasonic sensors and padded silicone skin. This robot is designed to look after vulnerable people, so it has a sculpted, curved body and head to appear more friendly.

by numbers

841,000
Estimated number of entertainment robots that were sold in 2011

5
Predicted percentage of average rise in sales of robots per year

9.8 million
Estimated number of domestic robots that will be sold between 2011 and 2014

25.5 billion
Estimated worldwide market value for robotic systems in 2011 in US dollars

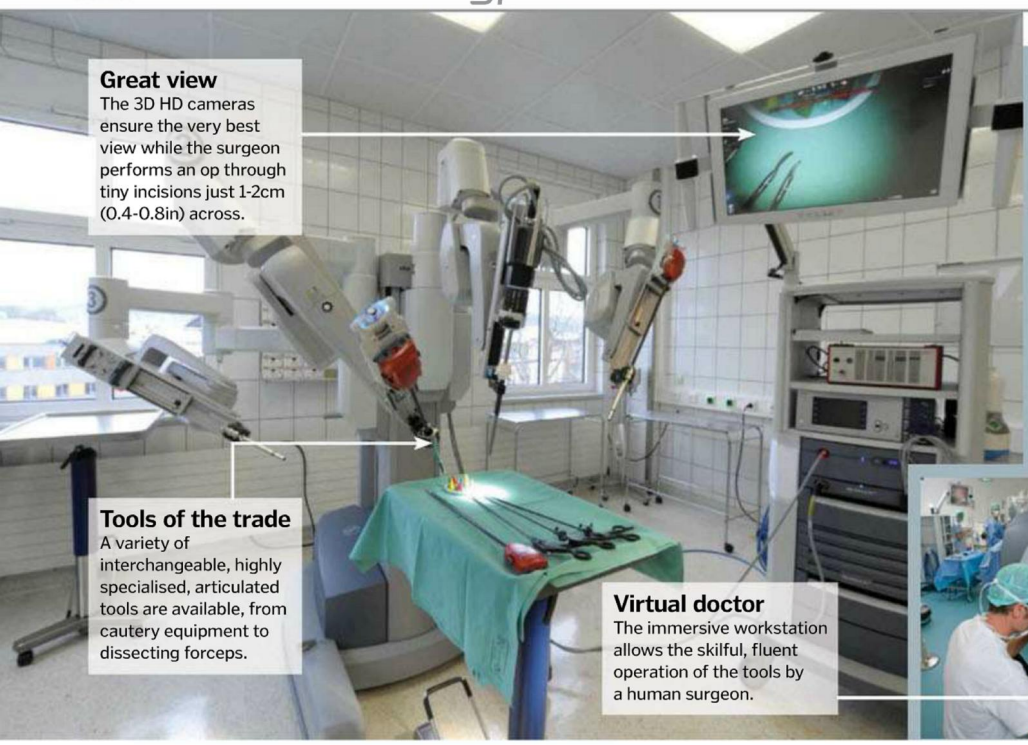
13
Percentage increase in sales of medical robots in 2011

40
Percentage of total number of service robots in defence applications

© Sugano Lab, Waseda University; Boston Dynamics; iRobot; E.zicom Robotics; NASA

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"The MQ-9 makes efficient use of its airframe to pack a huge array of sensors, weapons and fuel"



Great view
The 3D HD cameras ensure the very best view while the surgeon performs an op through tiny incisions just 1-2cm (0.4-0.8in) across.

Tools of the trade
A variety of interchangeable, highly specialised, articulated tools are available, from cautery equipment to dissecting forceps.

Virtual doctor
The immersive workstation allows the skilful, fluent operation of the tools by a human surgeon.

DA VINCI SURGICAL SYSTEM
The surgeon

A steady hand, 3D HD vision and great dexterity make this one smooth operator

- ✓ Helps save lives
- ✓ Controllable over great distances
- ✗ Substitute for medical advice

If there is one person you need to trust, it's the surgeon operating on you or a loved one. Using the da Vinci Surgical System, the patient undergoes keyhole surgery by the robot, but this is controlled by the hand movements of a surgeon sitting in a control booth. These movements are measured and modified to reduce hand tremors or sensitivity, and then performed by the robot, meaning the da Vinci Surgical System is actually better with the tools than the surgeon controlling it. Doctors can conduct operations from a booth anywhere in the world thanks to the 3D high-definition display and cameras, though typically they will be sitting just a few metres away, in case of complications.

© Corbis

PREDATOR MQ-9 REAPER
The aerial assassin



Explore the pilotless vehicle which can soar across enemy lines and take out a target with deadly accuracy

✓ Flies autonomously ✓ Remotely bombs hostiles ✓ Provides real-time intel

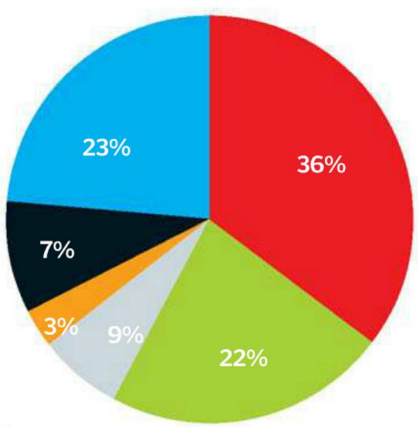
This unmanned aerial vehicle (UAV) has proved to be one of the most important military systems in recent years. Having no pilot to worry about, the MQ-9 makes efficient use of the conventional airframe to pack a huge array of sensors, weapons and fuel into a relatively small aircraft. Driven by a 708-kilowatt (950-horsepower) turboprop engine, electrical power is generated to run the on-board sensor and communication array, as well as the electrically actuated flight control surfaces, which are doubled up for redundancy. The UAV can function almost wholly autonomously, with an effective autopilot and auto-land capability, but due to the weapons on board, it's never allowed to attack a target itself. Using a secure satellite communications system thousands of kilometres away, human operators take control – in a similar way to flying a model aircraft – and command the Reaper to deploy its missiles.



The Reaper, formerly known as the Predator B, is made by General Atomics and has a top airspeed of 240 knots (444km/h; 276mph)

Industry robot sales breakdown

Take a quick look at the main areas in which industrial robots were employed in 2011



Key:
Automotive, Electronics, Chemical, rubber & plastics, Food & beverage, Metal & machinery, Other

Source: International Federation of Robotics

Jobs for the bots

Could that job be carried out by a robot? In



© Corbis

Babysitter
PaPeRo
NEC's PaPeRo robot has many of the abilities of a babysitter. It can tell stories, play games and – most importantly – track the movement of children via its RFID chips.

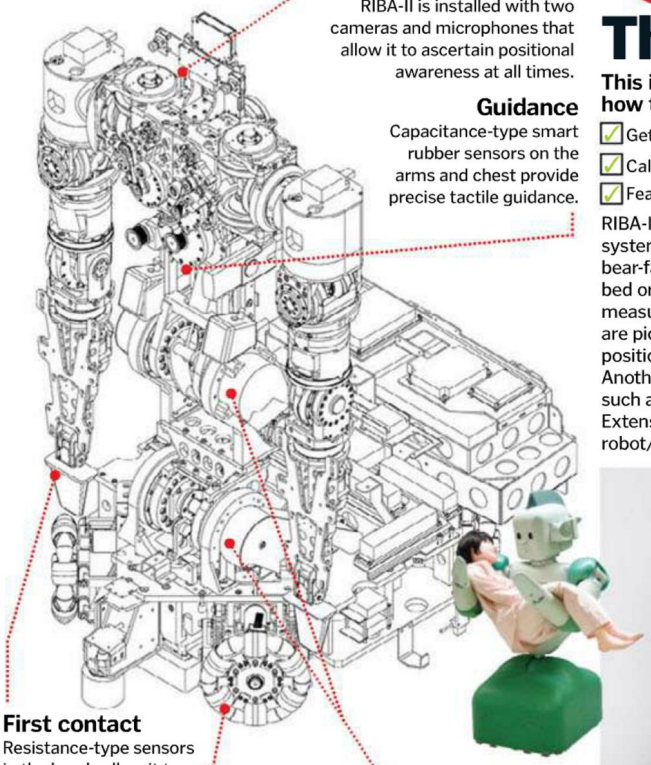
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THE STATS
710 WARRIOR

SPEED 12.9km/h | WEIGHT **226.8kg** | LIFT CAPACITY 137.1kg
RUNTIME **10 hours** | RECEPTION RANGE 800m | SLOPES **45°**

DID YOU KNOW? *Using the da Vinci Surgical System, surgeons on opposite sides of the world can work together at once*

Inside RIBA-II



Audio and vision
RIBA-II is installed with two cameras and microphones that allow it to ascertain positional awareness at all times.

Guidance
Capacitance-type smart rubber sensors on the arms and chest provide precise tactile guidance.

First contact
Resistance-type sensors in the hands allow it to detect contact with patients or barriers.

Mobility
Four omni-wheels help it to navigate narrow gaps and passages.

Joints
Mechanised joints in the base and lower back enable the robot to crouch down and lift patients even from floor level.

RIBA-II

The lifesaver

This intelligent lifting robot is revolutionising how the convalescing get about in hospital

- ✓ Gets you out of bed in the morning
- ✓ Calculates your weight
- ✓ Features sensors made entirely of rubber

RIBA-II is an electrically powered robotic lifting system designed to reduce injuries in carework. The bear-faced bot safely lifts patients from floor level into bed or onto chairs. His computer and sensors measure the weight and balance of the patient as they are picked up, and RIBA-II calculates the correct positioning of the arms to provide a comfortable lift. Another benefit is the increased dignity offered by such a system, which is very important to patients. Extensive research continues in this exciting area of robot/patient trust and interaction.



RIBA-II is a new-and-improved version of RI-MAN (the green robot just above) with a far greater range of capabilities

E.ZICLEAN WINDORO

The window cleaner

The bot offering a window into the future of domestic help

✓ Perfectionist ✓ Good sticking power ✓ Can be remote controlled

The Windoro is an autonomous window cleaner, similar in concept to the robot vacuum cleaner. The primary unit operates on the inside of the glass, and contains the electric motors, gears and wheels that drive it around the window. Scrubbing the glass with rotating brushes, the electronics send power to the two drive motors to make it follow a pre-programmed pattern that doesn't miss a spot. The slave unit is towed around on the outside using powerful neodymium magnets that also hold both parts tightly against the smooth surface, just like a giant magnetic fish-tank cleaner.

Magnets
Neodymium magnets mean the Windoro will stay in place on the window even when the batteries run out.

Smart
It autonomously measures the window and works out the best pattern for cleaning all of the glass.



Reservoir
An integral water tank in each unit holds the cleaning fluid and water, for a streak-free finish.

The best of the rest...



1 Kod*lab 'cat-bot'
To avoid getting stuck on its back, this modified version of the X-RHex has a swinging counterweight, used as a precisely controlled tail to orientate the body so that it always lands on its feet.

2 USC BioTac
This clever robo-finger mimics human fingerprints to generate a measurable vibration that is different for every texture. It builds up a database of tested materials.

3 Superhydrophonic bot (Harbin Institute)
Ideal for reconnaissance, water content measurement and wildlife research, this tiny bot can walk on water by exploiting surface tension.

4 BD SandFlea
This wheeled robot looks quite conventional, until it reaches a wall. Pointing itself upwards, the computer calculates the angle and power required before leaping up to eight metres (26 feet) into the air.



5 Kuratas
This four-metre (13.2-foot) monster is for one purpose only: to show off. Bottle rocket launchers and twin BB guns will get everybody's attention as you sit behind the full-colour display to control it.



© General Atomics; RIKEN; Kod*lab, University of Pennsylvania; Boston Dynamics; E.ziclean Robotics

which vocations are humans being replaced by bots?



© Corbis

Pharmacist
UCSF Medical Center
The UCSF Medical Center has a robotics-controlled pharmacy that can pick, package and dispense pills. The system has so far prepared in excess of 350,000 prescriptions.



© Claudia Heinstein

Cabbie
Autonomous driverless car
Self-driving cars are an option for taxi companies with their low fuel costs and insurance policies, if they're ever legalised worldwide.

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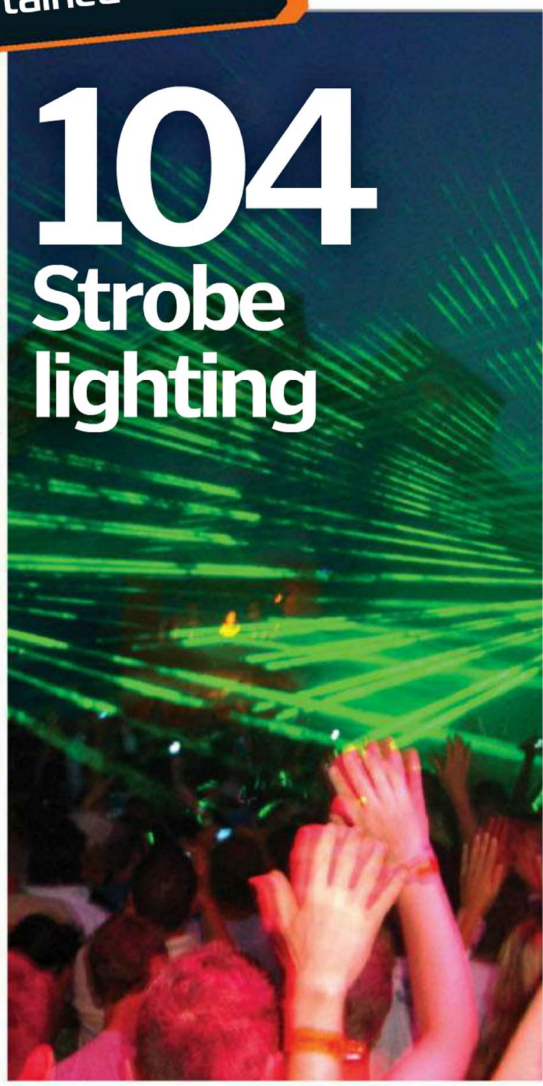
HOW IT WORKS

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"The Wii U is the first Nintendo console to feature full high-definition graphics"

Exploring the Wii U

What technology goes into Nintendo's newest console? We lift the lid to find out...

The latest games console from Nintendo is the first in what is considered the eighth generation, which all began with the Magnavox Odyssey and Atari's Pong home console in the Seventies.

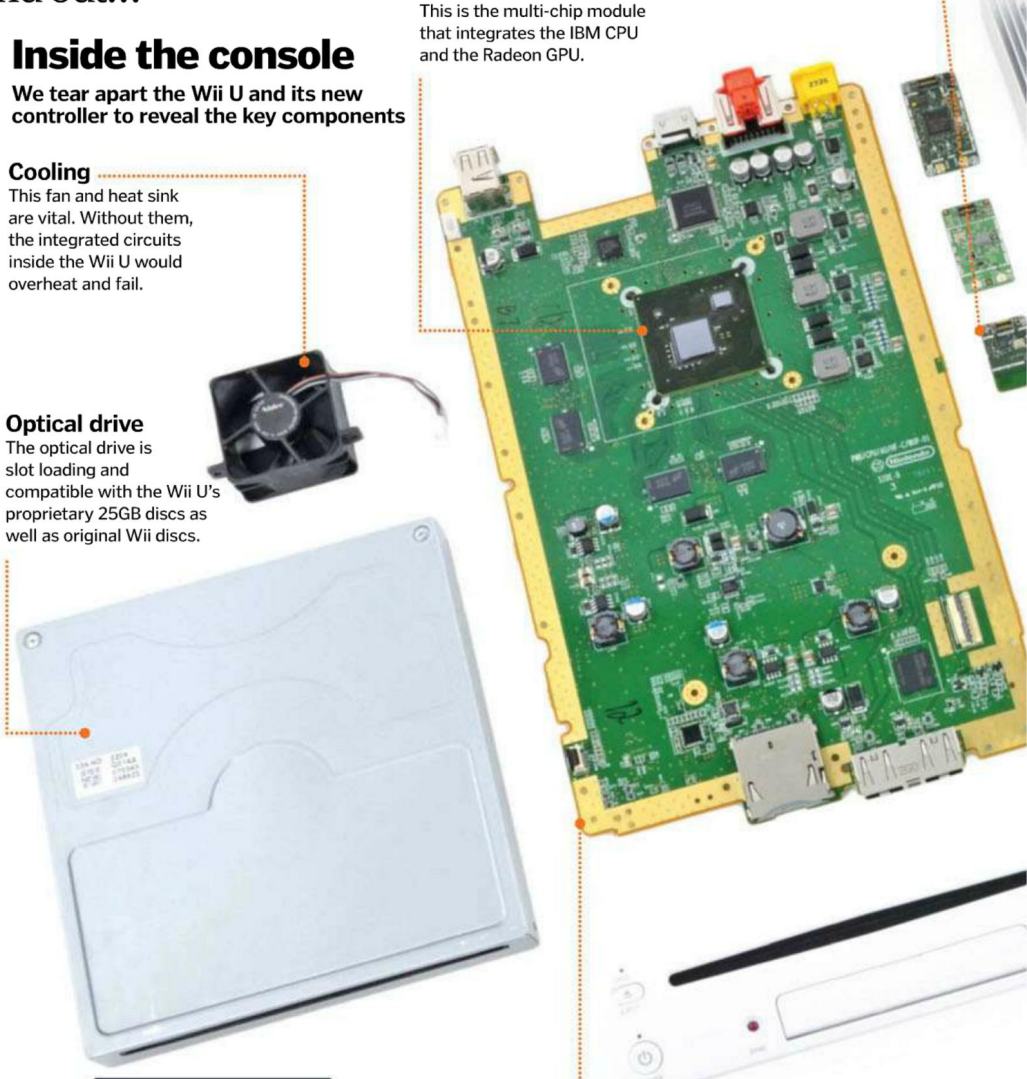
There are two main parts to the Wii U console: the box with the Wii U optical disc drive that forms the traditional console hub, and the very non-traditional peripheral Wii U GamePad.

The hub contains the main components and is the first Nintendo console to feature full high-definition graphics, with an output supporting up to 1080p resolution. The basic version of the Wii U features a fairly limited eight gigabytes of internal flash memory, but it's expandable with USB hard drives up to two terabytes – an ample maximum capacity for the game downloads, video storage and more that you're able to save on this machine, which should satisfy even the most avid gamer's needs.

It has a 45-nanometre, multi-core IBM CPU architecture – around half the manufacturing process size of the CPU in its predecessor (the Wii), which results in much greater processing efficiency. It has two gigabytes of DDR3 RAM – the 'memory' of the Wii U used for the dynamic storage of fast processes. Finally, its graphics processing unit (GPU) is based on AMD's Radeon technology, with bespoke video output for the Wii U. Interestingly, both the CPU and GPU are compiled onto one multi-chip module (MCM), creating a single integrated circuit that processes more quickly and, vitally, takes up less of the console's limited internal space.

Inside the console

We tear apart the Wii U and its new controller to reveal the key components



Wireless
These are the three Broadcom wireless modules that allow the Wii U to communicate across a LAN, Bluetooth 4.0 and 802.11n standard.

MCM
This is the multi-chip module that integrates the IBM CPU and the Radeon GPU.

Cooling
This fan and heat sink are vital. Without them, the integrated circuits inside the Wii U would overheat and fail.

Optical drive
The optical drive is slot loading and compatible with the Wii U's proprietary 25GB discs as well as original Wii discs.

Console motherboard
All the major components of the Wii U (CPU, RAM, etc) are brought together on this circuit board.



The statistics...

Wii U console

Dimensions: 26.7 x 17.2 x 4.5cm (10.5 x 6.8 x 1.8in)

Weight: 1.6kg (3.5lb)

Output: Up to 1,920 x 1,080px

Internal memory: 8GB (basic); 32GB (deluxe)

Wii U GamePad

Dimensions: 25.9 x 13.5 x 2.3cm (10.2 x 5.3 x 0.9in)

Weight: 491g (1.1lb)

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When was the Nintendo company founded?

A 1889 **B** 1951 **C** 1980



Answer:
Incredibly, Nintendo was founded in Japan as a card company as long ago as 1889. It was primarily a playing card manufacturer until it expanded into the electronic toy industry in the Sixties, turning its hand to videogames in the Seventies.

DID YOU KNOW? *It will be possible to pay for Nintendo Network downloads by placing an NFC credit card on the GamePad*



GamePad display
An LCD screen similar to those found on mobile gaming and smartphone devices is fused with a digitiser that allows for touch input.

NFC board
This is the GamePad's near-field communications board. It's currently unused but Nintendo has interesting plans for its future to enable quick-and-easy purchases.

GamePad motherboard
The GamePad has fewer integrated circuits than the console, but still needs a hub to plug them all into.

Wireless module
This module is used to communicate between the Wii U console and GamePad controller over a 5,150-5,250MHz frequency.

Battery
The Wii U GamePad has a rechargeable 3.7V battery that lasts between three and five hours depending on display brightness.

A spotlight on the software

The most powerful consoles in the world are nothing without adequate support from the software developed for them. The games launcher, the Nintendo Network and its features, as well as Nintendo's bespoke social network system, Miiverse, all sit on top of the Wii U operating system. It's a piece of proprietary software that Nintendo has code-named IOS – Internal Operating System – and, unusually, it runs using a dedicated ARM-based CPU separate from the IBM CPU used by game software. The advantage of this is that the Wii U can utilise the full processing capacity of its main CPU to tackle the most power-intensive games. Not only that, but unlike PCs and many other consoles, while a game is running, the Wii U can switch the IOS off and unload it from memory, allowing the game to make full use of the system RAM.



What's new with the Wii U GamePad?

The GamePad has an embedded 15.7-centimetre (6.2-inch) touchscreen that complements gameplay when the Wii U outputs to the television, and can be played even when the TV is off. It has many independent functions too, like stereo speakers and mic, volume control, a front-facing camera, infrared sensor strip and transceiver, wireless communications, rechargeable battery pack and, of course, lots of buttons. On top of this, it includes a near-field communications (NFC) chip that enables users to import content from supported devices simply by placing them onto the pad.

The Wii U GamePad is a far more sophisticated piece of kit than any console controller in history and can almost be considered a separate console in itself. Nintendo has made the device deliberately large and comprehensively featured to take the player's attention from the main console, which it refers to as the 'stagehand' – in other words, something that works unnoticed but plays an important role behind the scenes.

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"Analogue joysticks are used for programs where a much greater range of movement is required"

How does a gaming joystick work?

If you've ever wondered how that little stick can let you control a character or game on-screen, take a look at what's inside...

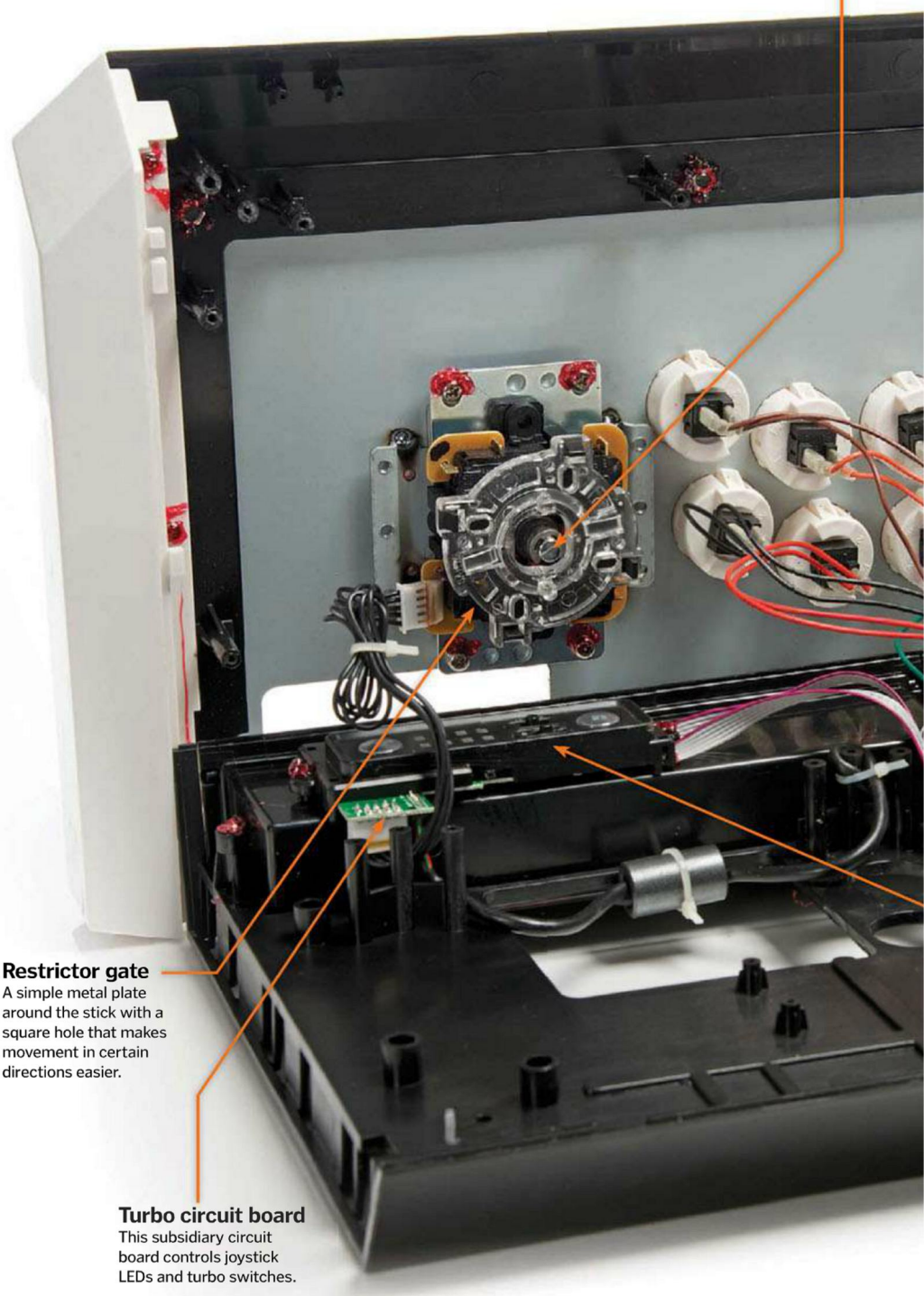
Joysticks essentially translate the movement of your hand into a digital format that a piece of software can then interpret to perform an action. They're used in a number of ways, from flying supersonic aircraft to controlling wheelchairs – to name just two – however joysticks are probably most commonly encountered as a major element of people's gaming systems.

Simple joysticks, such as the one used to control games on the early Atari consoles, employ electric switches to detect the direction you are holding the stick in.

Inside the base is a printed circuit board with contact terminals arranged around the bottom of the stick. While the joystick is in a neutral state (ie at the centre), or the stick isn't pressing the contacts into the 'on' position, the terminals cannot complete the electric circuit.

The gap in the circuit is closed when the terminals are pushed on, pressing a metal disc onto the board. The console then detects the charge on the wire and executes the appropriate action, whether that's moving left, right, up, down, diagonally or something completely different, depending on how the software interprets it. The buttons on the joystick – often used for actions other than movement – work in much the same way.

Analogue joysticks are used for programs where a much greater range of movement is required – like flight simulators. Instead of pressing buttons to complete circuits, the bottom of the stick slots into two shafts – one that pivots on the X axis and another on the Y axis – with springs that return the stick to a central position when released. A pair of potentiometers (variable resistors) track the location of these shafts and therefore determine the exact position that you're holding the joystick in.



Joystick
This uses four microswitches: right, left, up and down. Diagonals are determined when two switches are depressed at the same time.

Restrictor gate
A simple metal plate around the stick with a square hole that makes movement in certain directions easier.

Turbo circuit board
This subsidiary circuit board controls joystick LEDs and turbo switches.

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KEY DATES
JOYSTICK HISTORY

1926
The US Navy patents a two-axes joystick for use with remote-controlled aircraft.

1944
In Germany there's a patent for electric joystick anti-ship missiles and a guided munitions system.



1963
Beyond the RC model aircraft industry, joysticks begin to be used in powered wheelchairs such as the Permobil.

1972
The first games console, the Magnavox Odyssey (right), ships with an early form of gaming joystick.

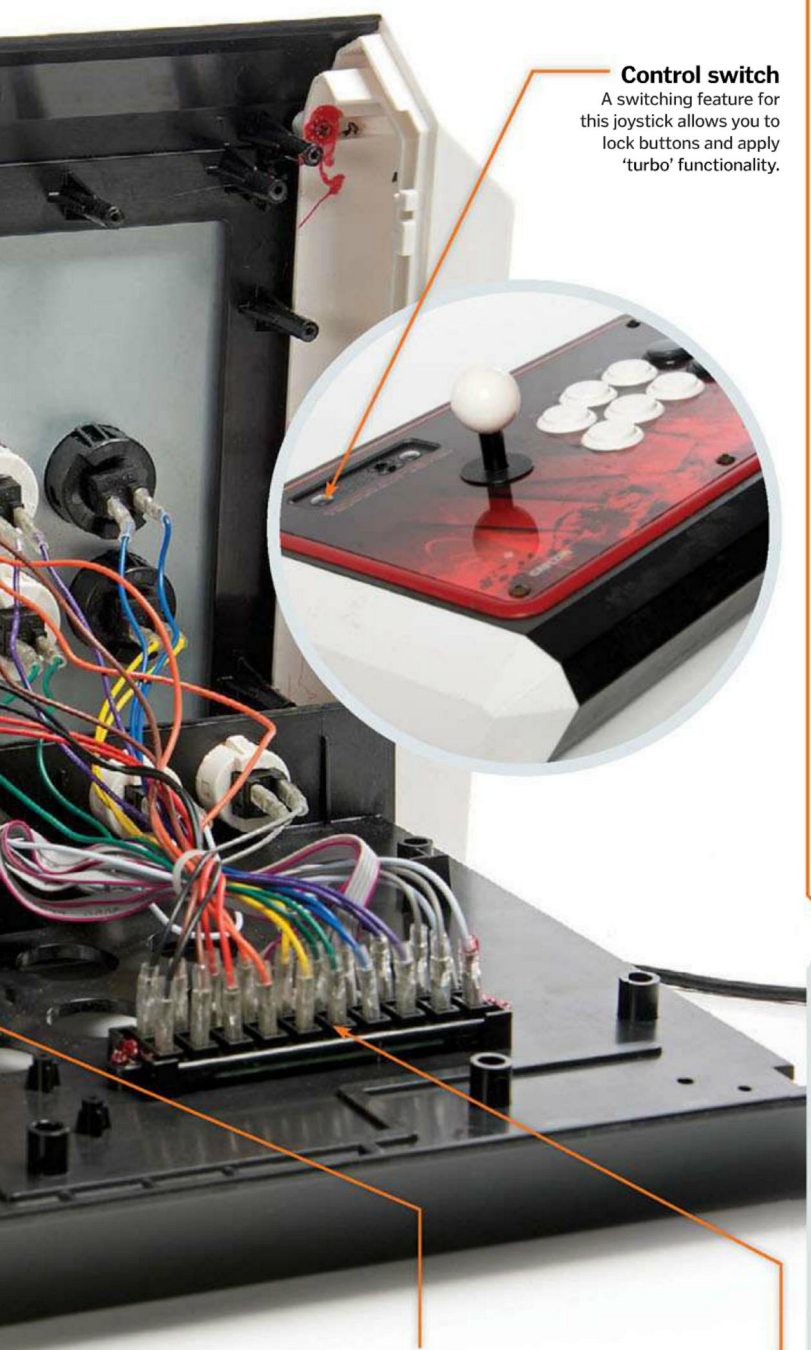


1977
Atari launches the Atari 2600 home console, with a distinctive one-button joystick controller.

DID YOU KNOW? *Joysticks were around for more than 40 years before videogames were invented*

Joystick teardown

The Street Fighter IV TE FightStick is a specialist joystick that uses traditional switch technology



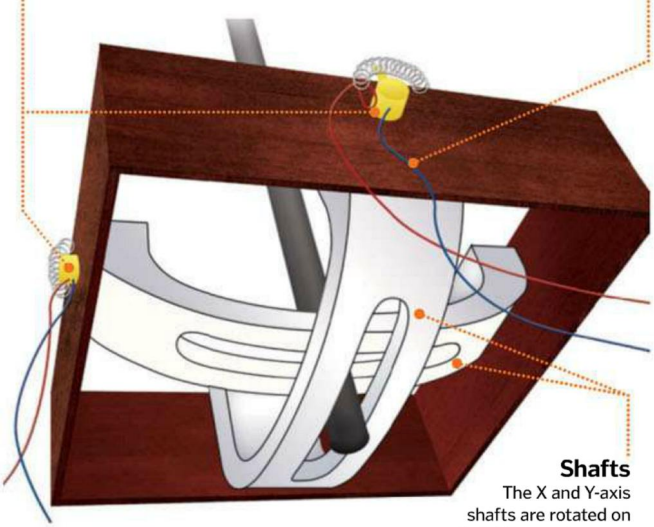
Control switch
A switching feature for this joystick allows you to lock buttons and apply 'turbo' functionality.

Main circuit board
Contains the processing elements of the joystick and circuit wiring for the buttons.

Terminal block
An intermediary piece of circuitry that connects buttons to the main circuit board.

Potentiometers
As the shafts are moved, contact arms on the pots move along a spring and alter the level of resistance.

Circuit wiring
As the circuit resistance is increased or decreased, a capacitor is charged more quickly or slowly accordingly.



Shafts
The X and Y-axis shafts are rotated on their hinges whenever the stick is moved.

The role of potentiometers

In an analogue joystick, as the base of the stick moves along the track of a shaft, a potentiometer (or pot) increases or decreases the resistance of the current in the X or Y-axis circuits accordingly. As opposed to the binary on and off state the contact terminals provide in a digital joystick, pots give an analogue range from the minimum value to the maximum value, depending on whether the stick is being pulled at its minimum range, its maximum range or somewhere in between. This signal still needs to be transformed into a digital numerical value though. A basic analogue-to-digital converter uses the voltage from the potentiometers to charge a capacitor, where a circuit with maximum resistance will charge more slowly than one with less resistance. By measuring the length of time the capacitor takes to charge fully, a numerical value can be ascertained.

Advanced joysticks

In old analogue joysticks the analogue-to-digital conversion is handed over to the console or computer, requiring the system to continuously request data from the joystick, known as 'polling', to detect its current position. This can be a drain on system resources, so newer joysticks include an analogue-to-digital converter chip that translates the signal for the computer.

Some of the latest joysticks avoid this problem altogether by using optical technology. The shafts are connected to slotted wheels, each placed between an LED with a photocell on the other side. When the wheel turns and a slot lines up with the cell, the light from the LED causes it to generate a current, switching off once it's blocked again. Cutting-edge joysticks like the Saitek X-65F (pictured) don't even have moving parts – instead they respond to pressure exerted on the stick, which is exactly the same system found in modern fighter jet planes.



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"Interaction is also being increased thanks to the adoption of touch-screen and touch-pad technology"

POWERFUL PORTABLE GAMING



Blurring the line between high-fidelity home console entertainment and the portability associated with phones and compact cameras, the new wave of handheld game consoles offer extreme levels of power and connectivity

It's been a good few years since Sony and Nintendo released their last respective portable gaming console families to the world (the Sony PSP and Nintendo DS). That's a relatively long time to most humans, but a comparable eon in terms of technology development.

Hardware and system software has developed at a rapid and constant rate, introducing innovative new ways to interact with increasingly impressive virtual worlds. Those worlds are becoming increasingly more accessible and believable, with enhanced graphical fidelity, audio and production values: the latter now approaching the level of Hollywood blockbuster movies. The time, therefore, has come for change.

And what change is being delivered. Back in 2011 Nintendo launched its revolutionary 3DS, a new and more powerful variant of the DSi handheld that can wondrously produce 3D graphics without any need for special glasses. It also released the 3DS XL in 2012. Not to be outdone, Sony announced its newest portable console, Vita, a system that boasts the raw power of a full-blown PlayStation 3 home console, but in a form factor that will slip effortlessly into your jeans' pocket. Home console motion-control technology is also being delivered, with both systems including state-of-the-art sensor arrays such as gyroscopes, electronic compasses and accelerometers that allow users to physically affect their virtual worlds in real-time, utilising the devices as an extra level of total control. The device was released back in 2012, with impressive sales showing people were ready for a change.

Interaction is also being increased on these cutting-edge systems thanks to the adoption of touch-screen and touch-pad technology. In terms of gaming, think climbing over obstacles in the adventure title *Uncharted* with just a flick of the

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5 TOP FACTS
CURRENT-GEN HANDHELDS

Old hat
1 Nintendo's exploration of 3D is nothing new, with Grand Prix II: 3D Hot Rally released in the late Eighties. The game used liquid crystal shutter goggles to make imagery appear 3D.

3G
2 The Sony Vita comes in two SKUs, one with 3G support and a cheaper version without. 3G support is contract-based and provides users with web access regardless of Wi-Fi.

1:1
3 3DS charge time is around 3.5 hours – the same as its battery duration when 3D is enabled. With 3D off, this increases to 5-8 hours dependent on screen brightness.

Game master flash
4 The Vita utilises flash-memory NVG cards to provide game media. These come in 2GB and 4GB, ten per cent of each writable for save game files and post-release patches.

Pied piper
5 Due to the autostereoscopic effect used to generate the 3DS's imagery, Nintendo has stated that it's not intended for children under six, as it may harm their developing vision.

DID YOU KNOW? *The original Game Boy was released on 21 April 1989*

The statistics...



Nintendo 3DS

Cost: £133
Release date: 23 March 2011
Height: 2.9 inches
Length: 5.3 inches
Depth: 0.8 inches
Weight: 226g
Screen size: 3.53 inches (upper), 3.02 inches (lower)
Processor: 1,048 OH ARM CPU
Battery: 3.7V 1300mAh 5Wh li-ion

Inside the 3DS

We crack open the Nintendo 3DS to reveal its tech and features

Sensors
Recording duties are handled by a UC CTR 041KM73 KG10 chipset (temperature moitoring, etc), while positional awareness of the device – which is necessary for motion control and AR gaming – is handled by an Invensense ITG-3270 MEMS Gyroscope unit.

Learn more
For more info and images of the Nintendo 3DS, visit the gadget surgeons at **ifixit.com** who kindly contributed photos and findings for this article.

iFixit

Battery
The 3DS comes packed with a 3.7V 1300mAh 5Wh li-ion battery that provides a limited three to five hours battery life when the 3D-adjustometer is switched on. This increases to five to eight hours if 3D is switched off, though overall life will decrease with each charge of the unit.



Processing
Processing power is generated from the central Nintendo 1048 OH ARM CPU, a chip that works in tandem with the 3DS's DMP PICA200 graphics processing unit. On-board RAM comes courtesy of a Toshiba-brand NAND flash solid-state array.

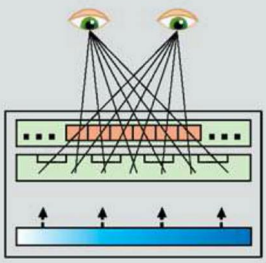
Screens
The 3DS has two screens. The lower LCD is 2.42" x 1.81", has a pixel resolution of 320 x 240 and is capable of displaying 16.77 million colours. The top LCD screen is 3.02" x 1.81", has a pixel resolution of 800 x 240 and is integrated with a parallax barrier, the technology used to generate the 3D effect.

Connectivity
The 3D's Wi-Fi connection comes courtesy of an Atheros AR6014 IC 802.11 b/g chip, which is installed with one antenna. Its infrared connection is provided by a tiny NXP-brand S7500803TSD031C chip. An SD card memory reader is installed on the side of the device.

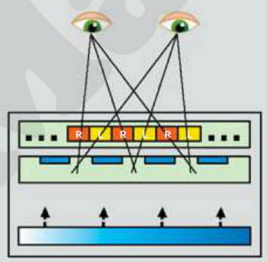
"The Nintendo 3DS uses a 'parallax barrier' to generate its 3D effect"

How does the 3D work?

The 3DS uses a 'parallax barrier' to generate its 3D effect. This is a process that generates a stereoscopic image displayable to the user without the need to wear 3D glasses. The barrier is a layer integrated into the screen consisting of a series of precision slits, which when made solid (usually controlled by liquid crystal) separates the light rays emanating from the screen's backlight into two sets of viewable pixels, one seen by each eye. This creates a false sense of depth through parallax (displacement of position), tricking the brain into perceiving two images where there is really just one.



2D display mode
When the 3D-adjustometer toggle is switched to off, the liquid crystal layer is adjusted to make the parallax barrier transparent, allowing light to pass right through it. This causes the same image to be seen by both the left and right eye of the user, presenting a traditional backlit two-dimensional display.



3D display mode
However, when the 3D toggle is switched to on, the liquid crystal is adjusted to create a solid parallax barrier, separating the backlight's projected rays into two images. This causes different images to be seen by the right and left eyes of the user, creating a sense of depth and therefore a three-dimensional effect.

finger, or climbing vines and walls by sliding your fingers up or down the Vita's rear touchpads. This technology doesn't just aid gaming either, with both systems sporting fully optimised touch-screen user interfaces and menu systems, offering scrolling, swapping and selection with a simple movement of your finger or stylus.

Smartphone levels of connectivity are also being delivered, with devices capable of connecting to the internet via Wi-Fi and 3G (Vita only), as well as to each other via Wi-Fi, Bluetooth and infrared connection. This is opening up these handheld devices to another feature traditionally associated with non-mobile platforms – downloadable games and media. No longer will entertainment be locked solely to physical memory cards and cartridges, but expanded to the entirety of the web, with software downloadable to the devices from online eShops such as the PlayStation Store. Partner this with both the 3DS and Vita revelling in their backwards capability with previous console titles (portable or not) as well as awesome multimedia capability, available to download and play movies and music instantly from services such as Netflix, and the idea of one, all-encompassing entertainment device seems to transition more and more from fantasy to reality.

Read on as we deliver an in-depth analysis of the handheld's hardware, software and features, to see how they revolutionised the way you play games.

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"Motion control technology is also being delivered with both systems, including state-of-the-art sensor arrays"



Augmented reality

Both new consoles support it, but what does it actually do?

Augmented reality (AR) describes a process where the physical, real world is augmented (added to) by audio/visual computer-generated sensory inputs. AR adds an extra visible or audible layer of information onto the world, usually through a camera/display setup.

Both the Vita and 3DS are using this technology to create a new augmented reality gaming experience, blurring the line between fantasy and reality. A good example can be seen in the AR target shooting game cards, packaged with every new 3DS. Here users place a matchbox-sized card on a regular surface, before holding up their 3DS's camera to it so that it appears on screen. Next, due to a combination of the 3DS's camera, motion sensor and electronic compass, as well as specialised software, the card transforms into a target shoot, with 3D monsters and objects growing out of the chosen surface. The game remains virtual, but is now set upon a real background.

Vita explained

Sporting a raft of new features, controls and technology, the Sony PlayStation Vita is one of the most powerful handhelds on the planet



Screen

The Vita sports a massive five-inch OLED capacitive touch-screen display, capable of reproducing 16 million colours. It has a native resolution of 960 x 544 pixels and boasts 220 pixels per inch of screen.

Software

The Vita boasts a brand new touch interface and menu UI, replacing the PSP and PS3's XrossMediaBar. While games will be sold in stores on the new NVG flash card format, titles will also be available directly for download via the PlayStation Store.

Processing

Processing power is delivered by a state-of-the-art quad core ARM Cortex-A9 MPCore CPU, while graphics are handled by a powerful SGX543MP4+ GPU capable of generating 133 million polygons a second.

Connectivity

The Vita can connect to the internet and other devices via Wi-Fi, 3G mobile (with contract) and Bluetooth. Media can be loaded onto the device via Sony's Vita card flash memory.

Sensors

As well as a front and rear camera, rear touchpad, microphone, stereo speakers and electronic compass, the Vita is installed with a Sixaxis motion sensing system, comprising of a three-axis gyroscope and three-axis accelerometer.

The statistics...

Sony PlayStation Vita

- **Cost:** £169.99 (Wi-Fi + 3G)
- **Release date:** 22 February 2012
- **Height:** 3.3 inches
- **Length:** 7.2 inches
- **Depth:** 0.73 inches
- **Weight:** 279g (Wi-Fi + 3G)
- **Screen size:** 5 inches
- **Processor:** Quad-core ARM Cortex-A9
- **Battery:** n/a

All Vita pics © Sony

HISTORY OF PORTABLE GAMING TECHNOLOGY

Portable hardware has evolved massively over the past 20 years...

1989



Game Boy

The original handheld console, the Game Boy offered 8-bit gaming classics like *Tetris* and *Super Mario Land*. It introduced a volume control dial, directional D-pad and contrast slider. Multiplayer was enabled by a link cable.

1990



Sega Game Gear

Sega's version of the Game Boy, the Game Gear offered a portable variant of its popular Master System console. Colour was a big selling point (not available on the original Game Boy), as well as its ability to deliver stereo sound through headphones.

1999



Neo Geo Pocket Color

A 16-bit portable gaming handheld produced by SNK, the Neo Geo Pocket Color packed greater RAM, CPU speed and resolution over previous handhelds. It also allowed for a wired connection to Sega's full-size Dreamcast console.

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1. PHONE

Xperia Play
A much-rumoured phone/PSP hybrid, the Sony Ericsson Xperia Play allows users to make a call and then play titles such as God Of War and Monster Hunter.



2. TABLET

iPad 4
Apple's new, thinner iPad has access to Apple's catalogue of games via the App Store. Top hits include Angry Birds, Tiny Wings and Fruit Ninja.



3. HANDHELD

Nintendo DSi XL
Due to the release of the 3DS, Nintendo's existing DSi handhelds have seen their prices slashed. The DSi sports such hits as Super Mario Bros, Pokémon Black/White and Professor Layton.

DID YOU KNOW? *The Game Boy family of handhelds sold 118.69 million units worldwide*



Portable gaming has come a long way

THUMB WARS

We pit the two new portable contenders against each other in the ultimate stat showdown



Nintendo 3DS	VS	PlayStation Vita
		
Size		
2.9 x 5.3 x 0.8 inches		3.3 x 7.2 x 0.73 inches
Weight		
226g		279g (Wi-Fi + 3G)
Screen resolution		
800 x 240 (upper), 320 x 240 (lower)		960 x 544 @ 220ppi
Screen size		
3.53 inches (upper), 3.02 inches (lower)		5 inches
Processor		
Nintendo 1048 OH ARM CPU		Quad-core ARM Cortex-A9 CPU
Graphics chip		
DMP PICA200 GPU		543 MHz SGX543MP4+ GPU
Media input		
SD card, NAND flash		PS Vita card
Cameras		
Three, capturing at 640 x 480 resolution		Two (one front, one rear)
Touch screen		
Yes		Yes
Touchpad		
No		Yes
Motion sensor		
Yes		Yes
Electronic compass		
Yes		Yes
Wi-Fi		
2.4GHz (supports IEEE802.11 b/g with WPA™/WPA2™ encryption)		2.4GHz (supports IEEE802.11 b/g/n)
3G connection		
No		Yes – contract required
Infrared connection		
Yes		No
Battery life		
3-5 hours (3D), 5-8 hours (2D)		3-5 hours

Next-gen portable gaming



Check out some of the titles chosen to showboat each console's awesome new power



Super Street Fighter IV 3D Edition
A hotly anticipated launch title for the 3DS, this reworking of an old classic included all moves, characters and locations in 3D. A bespoke over-the-shoulder camera mode adds real depth.



Mario Kart 3DS
Mario and co return in glorious 3D to battle it out once more. With a reworked graphics engine, as well as better physics, audio and new tracks, *Mario Kart 3DS* was one of 2011's most anticipated titles.



Pokémon Black/White
While technically not utilising the 3DS's new technology, *Pokémon Black/White* is one of the DS family's best games of 2011 and offers a role-playing game centred on – you guessed it – catching 'em all.



Uncharted
The multi-game franchise crashed onto the Vita with *Uncharted: Golden Abyss* in 2012 (or late 2011 in Japan). The game featured incredibly visuals, and received high praise upon release.



LittleBigPlanet
Released in 2012, *LittleBigPlanet* made its appearance on Vita, a perfect game for the console. Addition content is also available to expand the game for those enthusiasts out there.



Metal Gear Solid
Used as a tech demo to show the Vita's PS3-level graphical power, *Metal Gear Solid 4* led analysts to believe that a new title was in the works. This was confirmed in 2013 at the Game Developers Conference.

2004


Nintendo DS
The original DS featured dual-screens, touch-screen technology, virtual surround sound, speech recognition, Wi-Fi connectivity and a control stylus. The system used proprietary solid-state mask ROM cards to deliver game media.

2004


Sony PSP
Sony's PlayStation Portable (PSP) offered a handheld variant of its PS2 console. It was the first handheld to use an optical disc format to deliver media, and sported an impressive 4.3-inch widescreen TFT LCD display.

2011


Nintendo 3DS
The fifth iteration of the DS handheld, the 3DS adds autostereoscopic 3D to its top screen. As well as being backwards compatible with the DS catalogue, the 3DS can play its own brand of 3D-enhanced titles such as *Super Street Fighter 3D*.

2012


Sony Vita
Released in the US and Europe in 2012, the Vita offers PS3 levels of graphical fidelity. It also features a 3G and Wi-Fi connection, five-inch OLED capacitive touch screen, six-axis motion sensor, three-axis compass and quad-core CPU.

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"Records work in a very similar, if a more tangible, way to the latest playback devices"

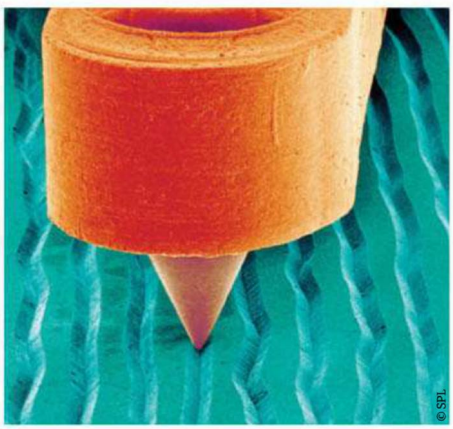
Record players

How sound is recorded and replayed from vinyl

Vinyl records are the audio storage media of yesteryear. You can think of them as MP3 players that simply store sound using a different system: older hard disk drives use magnetism to store this information, reading and writing using an arm that sweeps back and forth across spinning magnetic plates. Flash-memory music players (read: iPods and their contemporaries), meanwhile, make use of transistor technology to store digital music, while compact discs have tiny pits pressed into the silver layer by a laser, which can be read by a CD player.

Records work in a very similar, if a more tangible, way to the latest playback devices, though the same principles behind 19th-Century phonographs can be seen at work in modern turntables. The tiny grooves in the record vibrate a crystal in the stylus (needle) at the end of the arm as it moves across the record's surface. The resulting microscopic jolts move a metal bar that squeezes a piezoelectric crystal, generating an electric signal. The signal is fed to the amplifier that interprets it, then sends it out to the speakers which replicate the original sound.

Today's records are made of vinyl, pressed from a metal 'mother' that is cut using highly specialised machines. But even though the recording is of a much higher quality, you can still spin the turntable by hand to hear the record play without any intervention from modern technology.



© SPL

A shot taken by a scanning electron microscope of a stylus running along a groove in a record



This is a replica of Edison's tinfoil phonograph. Inset: Thomas Edison

© Gregory F Maxwell

Birth of the gramophone

In 1877, over a century before the dawn of digital music recording, Thomas Edison discovered that by attaching a needle to the diaphragm of a telephone receiver, a visual representation of the sound could be drawn when the needle vibrated along a cylinder covered in tinfoil. By attaching a horn and rotating the cylinder by hand, the sound could then be reproduced. Edison put his work on the phonograph on hiatus while he focused on electricity. In the meantime, Emile Berliner stepped in to create a more practical machine that used flat black discs, but could only play and not record. This was the gramophone and its records could be mass-produced via Berliner's Gramophone Company. The basic format for sound recording remained the same up until the Eighties, when cassette tapes became standard.



Record
The record is pressed from a 'biscuit' of vinyl, though they were first made of shellac, the resin from the Indian lac bug.

Record mat
A simple piece of textured rubber, but incredibly important as it stops the record from slipping on the turntable.

Motor
Powers the turntable via either a belt-driven or direct drive system.

Stylus
Tipped with a tiny diamond or hard mineral, the needle moves within the grooves on a record.

Cartridge
This is a plastic housing for the stylus that converts the vibrations from the contact with the record into electrical signals.

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$525,000

WORLD'S MOST EXPENSIVE RECORD

John Lennon and Yoko Ono's *Double Fantasy* album sold for over half a million in 1980. Why? It was owned by Lennon's assassin, Mark Chapman.

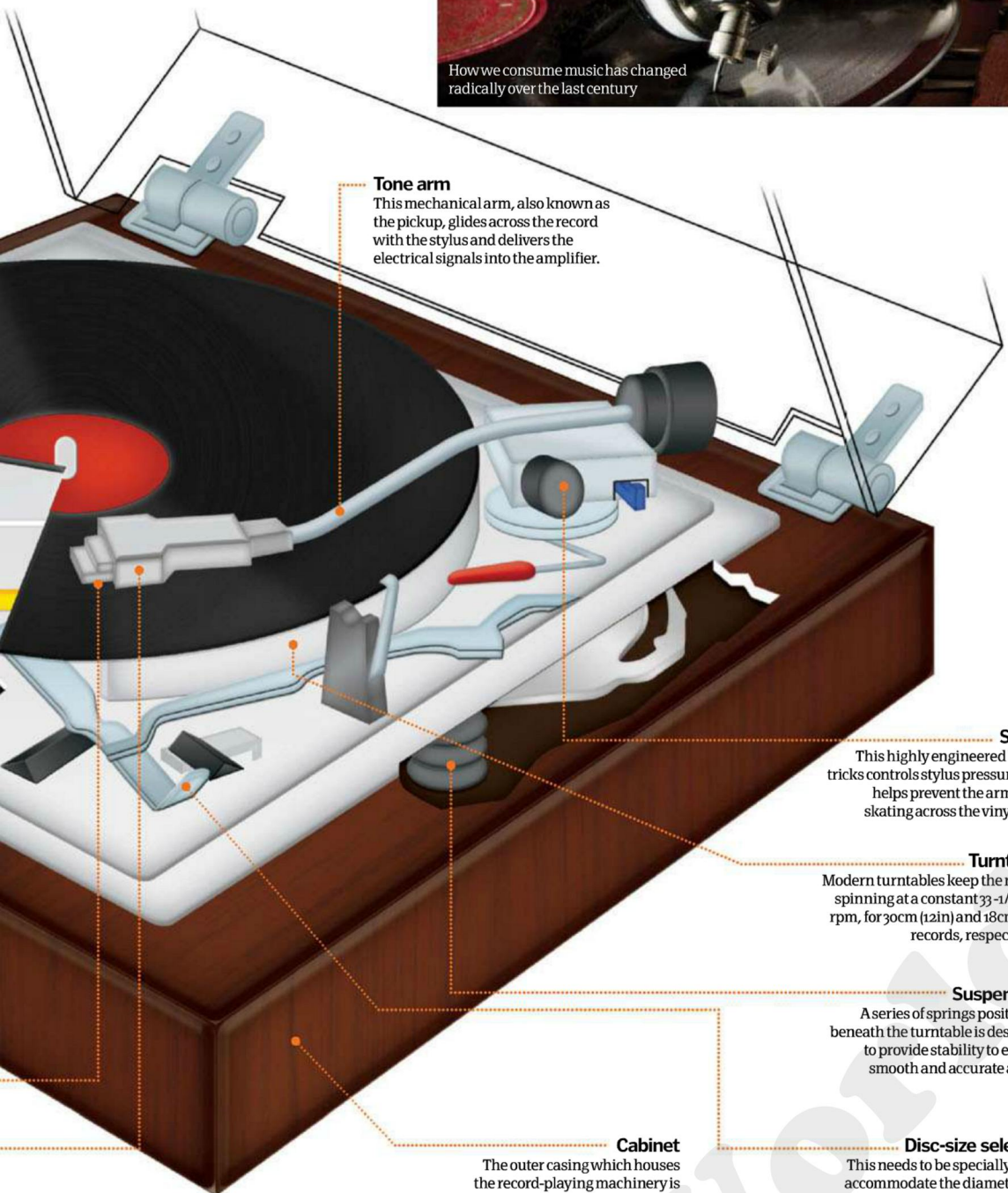
DID YOU KNOW? *The first recording of a human voice was made in 1860 by Édouard-Léon Scott de Martinville*

From disc to music

Take a look inside a record player and discover the key components



How we consume music has changed radically over the last century



Tone arm
This mechanical arm, also known as the pickup, glides across the record with the stylus and delivers the electrical signals into the amplifier.

Servo
This highly engineered box of tricks controls stylus pressure and helps prevent the arm from skating across the vinyl disc.

Turntable
Modern turntables keep the record spinning at a constant 33-1/3 or 45 rpm, for 30cm (12in) and 18cm (7in) records, respectively.

Suspension
A series of springs positioned beneath the turntable is designed to provide stability to ensure smooth and accurate audio.

Cabinet
The outer casing which houses the record-playing machinery is often made of top-quality wood, primarily for aesthetic purposes.

Disc-size selector
This needs to be specially set to accommodate the diameter of a record and is connected to the auto/manual operating lever.



World's most-famous record

Probably the most-recognised record in the world (and beyond) is the Golden Record that was placed aboard the Voyager 1 and 2 spacecraft. It is a 30-centimetre (12-inch) copper phonograph plated with gold and on it is recorded sounds, music and greetings from Earth in 55 languages, including: Beethoven's Fifth Symphony, "Hello from the children of planet Earth" in English and the sound of crickets and frogs. It is encased in an aluminium jacket and includes a needle and cartridge along with instructions for any intelligent extra-terrestrial life that happens upon Voyager on how to play the record. The record is designed to be played at 16-2/3 revolutions per minute – half the speed of the 33-1/3 standard for a commercial 12-inch vinyl. Since its launch in 1977, Voyager 1 has travelled nearly 18 billion kilometres (11 billion miles), making the Golden Record one of the few manmade objects to have left the solar system.

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"300 to 500 different Walkmans have been produced that have included new media formats"

The Sony Walkman

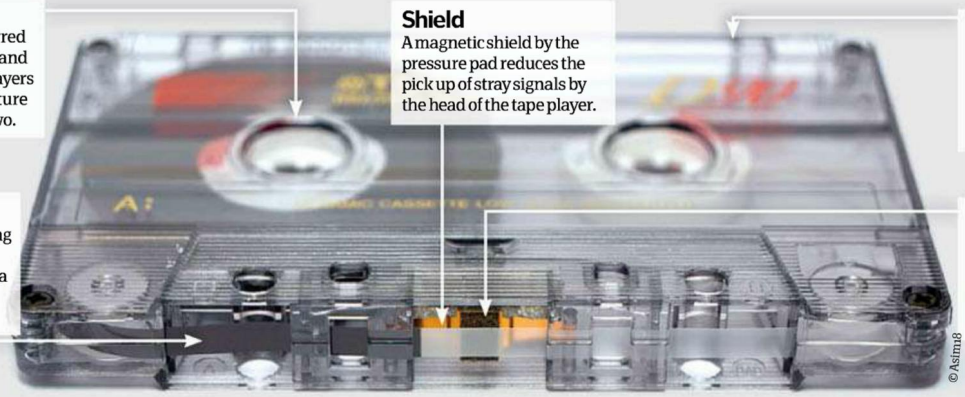
Inside the world's first commercial portable and personal stereo cassette player

For 20 years after its introduction in 1979, the Walkman dominated the personal stereo market. The first Walkman (TPS-L2) had two mini headphone jacks that enabled two people to simultaneously listen to it through Sony's new lightweight 50-gram (1.8-ounce) MDR-3L2 headphones.

The blue and silver metal-cased unit measured 88 x 133.5 x 29mm (3.5 x 5.25 x 1.15in), weighed only 391 grams (13.8 ounces) and was powered by two AA batteries, making it light, compact and easily portable. It could also be powered by a 3v DC adaptor (which wasn't supplied).

It contained a stereo tape head that played standard compact audiocassette tapes at a frequency response rate of 40Hz-12kHz. 300 to 500 different Walkman models have been produced that have since included new media formats like MiniDiscs and CDs, but it was only in 2010 that the cassette-based Walkman ceased production in Japan. New rivals like the introduction of Apple's iPod digital music player in 2001 and the increasing sophistication of mobile phones helped put the Walkman brand in the shade.





Inside audio cassettes

A staple consumer technology between the Sixties and Nineties

A popular item in many homes in the 20th Century, audio cassettes are plastic containers that store and distribute magnetic tape, a medium for the recording and playback of audible data. The tape is made from a polyester plastic film with a magnetic coating of ferric oxide powder. The oxide is a ferromagnetic material, a substance that when exposed to a magnetic field, becomes magnetised by it. This is what allows sounds to be captured and stored.

Playback from cassettes is achieved with an electromagnet. The magnet, which is at the fore of the recorder's/player's head, initialises a magnetic flux and applies it to the tape. During recording, the audio signal is sent through the head and magnetised onto the tape. During playback, the signal is transferred from the streaming tape by the magnetic field, and onto the player's head. The signal is then transferred to the player's speakers for playback.

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Digital Audio Broadcasting

What is digital radio and how does it work?



2x © Roberts

DAB radios offer more stations than standard FM varieties due to reduced co-channel interference

Digital Audio Broadcasting (DAB) is an increasingly widely adopted format used to transmit audio to radio sets. In contrast to FM radio, which remains the favoured standard worldwide, DAB is transmitted at a far higher frequency range and employs far greater data compression algorithms and audio codecs. This grants the format both major advantages and disadvantages over transmission on standard FM and AM formats.

DAB's key advantage is that through the use of multiplexing – a process of grouping various data streams into one signal – and compression (in the form of specific audio codecs and small bit rates), a large selection of radio channels can be packed into a narrow band of broadcastable frequency. This means that more channels can be broadcast over a smaller area and, crucially, without interference.

This lack of interference is another major benefit of DAB and is achieved through Coded Orthogonal Frequency Division Multiplex (COFDM). This technology splits the DAB signal across multiple frequencies and also across time, meaning that if one part of a station's signal is disturbed by interference (for example, the signal bouncing off buildings) then it can still be recovered by the receiver from another time or place.

Unfortunately, as DAB is still an evolving technology, the major downside with the format is that in some cases the compressed audio stream can result in worse audio fidelity than over standard FM radio. Recently, however, the DAB+ standard was introduced, which utilises a more advanced audio codec (HE-AAC v2) to improve audio quality while keeping the stream bit rate low.





Classic jukeboxes explained

Combining the traditional Fifties jukebox look with the convenience and quality of CD technology

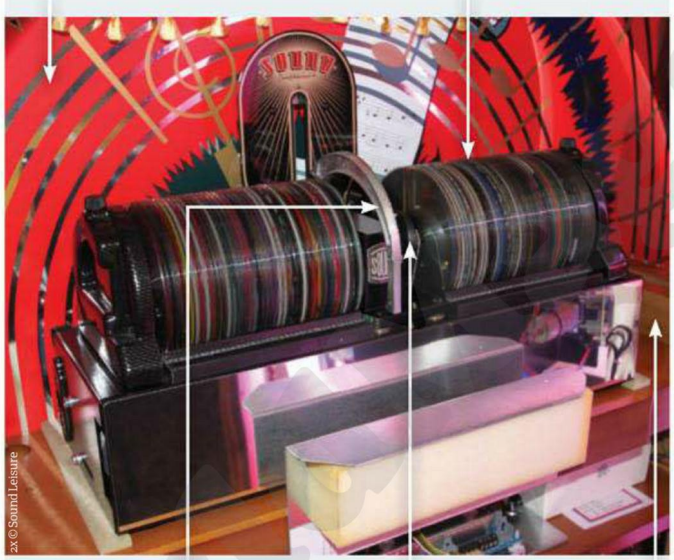
This type of jukebox, with a 21st-century inner mechanism, holds 80 compact discs (CDs) stacked horizontally on a slotted rack. When switched on, the pick-up mechanism runs on a track to the end of the rack, and then a sensor sends it 40 spaces to the centre of the rack. After a CD or song is selected on the panel of the jukebox, or via a remote-control unit, a location wheel on the pick-up mechanism sends it along its track to the correct CD location.

The pick-up mechanism lifts the selected disc, takes it back to the centre of the jukebox, and drops it down to the playback head. The CD playing head will scan the number of tracks on that disc and play the one that was selected. Once the track has finished the CD is lifted and returned to its original slot and the selection process is ready to start all over again.

Inside a CD jukebox

Domed top
The 'bubbler' top is styled after the classic 1946 Model 1015, which reflects the golden age of jukebox design.

CD rack
80 CDs are stacked vertically ready to be selected.



2x © Sound Leisure

Pick-up mechanism
A notched belt drive sends this along its track to select a CD. A location wheel that sends out a pulse every time it passes each CD slot guides it to the correct position.

Playback
The CD is lowered into the playback mechanism. This clamps the disc in position, scans it and plays the requested track.

Cabinet
A loudspeaker dominates the space below the bubbler top. Decorative tubes on the outside of the cabinet contain methylene chloride that is heated to generate a gas that creates a bubble effect.

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"Granting users the ability to have their digital library tagged and sorted via metadata tags"

How does iTunes work?

One of the most prolific media players on the market today, iTunes integrates a plethora of digital services into an easy-to-use interface, acting as a connections hub for a variety of hardware

iTunes is a propriety digital media player application created by Apple in 2001, which currently stands at the forefront of the digital music revolution. The software provides a free, user-friendly interface that people can use to play, organise and discover digital music and video files. They can then be synced across a broad range of static and mobile devices.

As well as providing a robust digital media player – enhanced by its ability to decode a variety of audio and video codecs and file formats including AAC, MP3 and MPEG-4 – the software also acts as an automatic data collator/provider, granting users the ability to have their digital library tagged and sorted via metadata tags. These are small pieces of data code that are attached to each file containing artist, album, track and artwork information, which are then grouped and sorted into an extensible markup language (XML) library – a set of rules for encoding documents in machine-readable form – that can be easily accessed by other software or hardware.

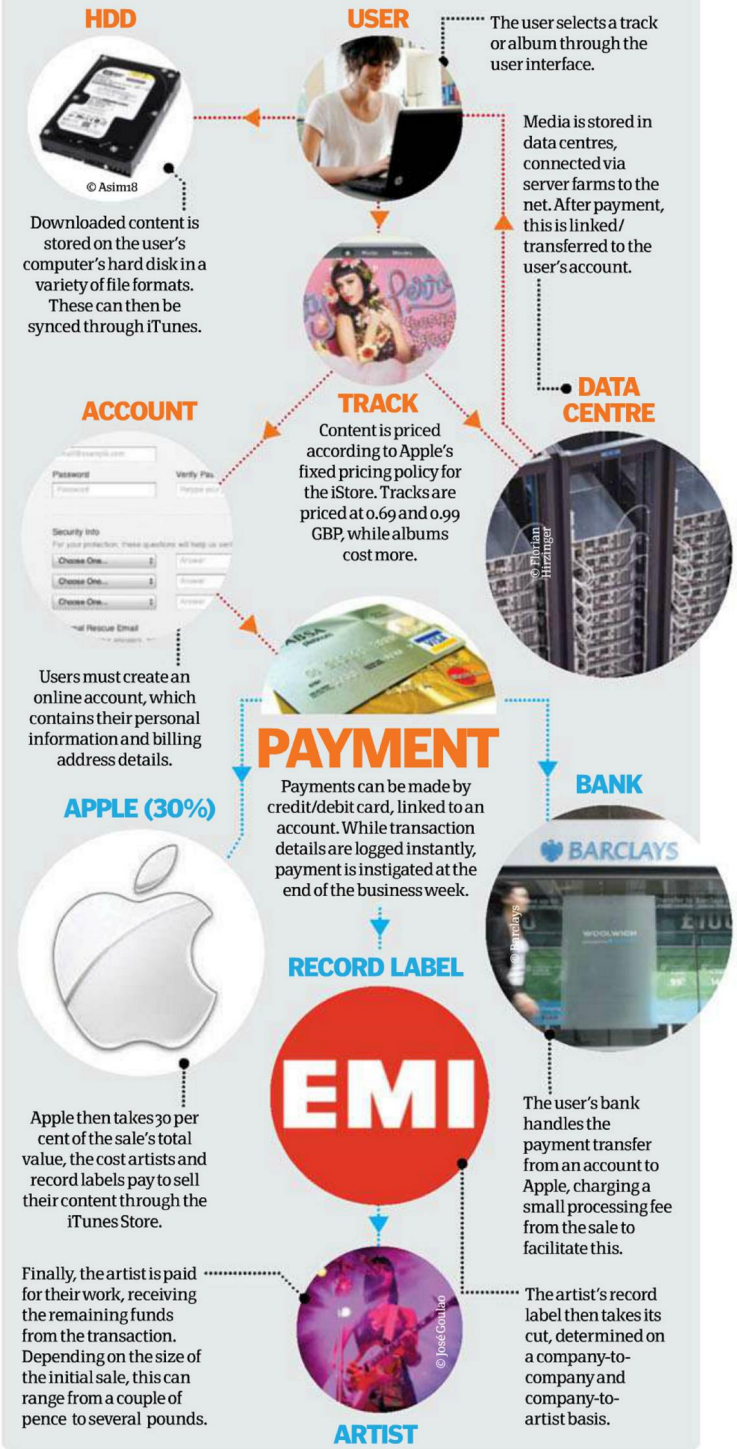
These organisational information protocols allow iTunes to act as a media hub, connecting a user's hardware such as their mobile phones, tablet computers and laptops together to share acquired content cross-platform, greatly increasing its accessibility. It also allows iTunes to integrate completely with Apple's own digital media delivery services, the iTunes and App Stores, drawing information and streaming content directly into the player for the user. Purchased music – which involves the user linking their bank account to the service – can then be directly downloaded onto the device on which iTunes is currently running, before being shared cross-platform as other auxiliary devices are synced with the software. iTunes also acts as an anchor point for any purchased new device, logging its registration code, unit and user's details for warranty/data-storage purposes.

As well as acting as a hub for digital media and hardware, iTunes also acts as a social networking hub, allowing users to generate, share and chat about digital media with their friends and other artists. This is achieved through the service's Genius and social networking features, which are directly integrated into the user interface – the former automatically generating a playlist of songs from the user's library of content, with the social networking options allowing users to review albums and share their favourite tracks and artists with their friends. These aspects of the software are particularly interesting, as they allow users to connect other data and informational services such as Twitter to their iTunes account.

Finally, iTunes has a common base, allowing it to be tailored to run on both desktop computer operating systems such as Microsoft Windows and Apple OS, as well as variants of it on mobile operating systems such as iOS. The most recent version of iTunes is iTunes 11, which was released in November 2012.

iTUNES PAYMENT PROCESS EXPLAINED

Each time a user purchases a track, a complex process of micropayments and data transfers begins



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5 TOP FACTS ITUNES

Jam
1 iTunes was based on Soundjam MP, a Mac OS-based audio player made by Casady & Greene in 1999. The software was bought by Apple in 2000 and built upon.

4.0
2 iTunes didn't have its now central store until V4.0, released in April 2003. The same year Apple included support for Microsoft's Windows XP and 2000.

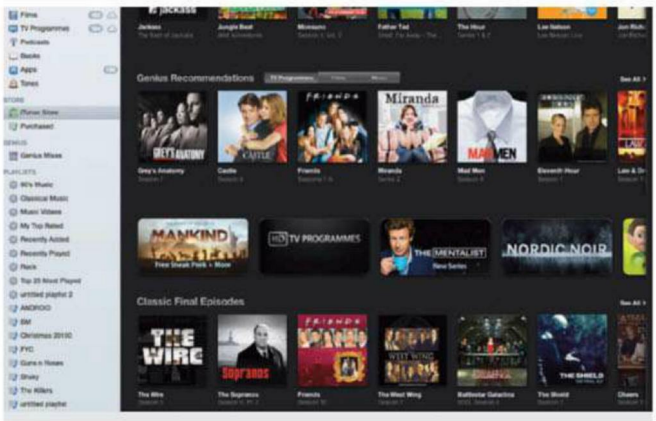
Support
3 Originally iTunes didn't support playback of many traditional file formats, preferring to convert any inputted file into AAC (advanced audio coding).

Genius
4 One of the most interesting additions to iTunes is Genius. This is an interface integrated playlist creator, which generates a music list based on the user selecting a track.

iTunes Match
5 The iTunes software is free to download, but users can pay £21.99/$24.99 a year to access Apple's iTunes Match service. It enables subscribers to access all songs from any compatible device.



The Genius feature allows users to discover new music



Users can now download TV episodes from the Store

Maximum connectivity

A quick look at how iTunes acts as the ultimate digital hub

Hardware
iTunes is designed with a common base that has been adapted to liaise with any Apple-connected device, ranging from laptops through to mobile phones and tablet computers. The software automatically syncs all data from these devices to the user's collection of apps and music files and vice versa, as well as checking for and updating their operating system software periodically. Many Apple devices are also activated through iTunes, with the service collecting registration and warranty information.

Playback
The original heart of the iTunes software is Apple's digital media player, which can decode a host of file formats for audio and video playback. Current supported formats include MP3, WAV and MPEG-4 among others, with the software interfacing with QuickTime codecs for video presentation. iTunes is also capable of acting as a CD/DVD player for physical media.



Stores
iTunes is now linked to Apple's iTunes and App Stores respectively. These act as media portals in which users can search for, trial and purchase music and apps for their desktop or mobile devices. The stores are integrated into the iTunes user interface as clickable tabs, and provide album art and information for other aspects of the software. Music is downloaded to the device, which can be shared DRM-free with other devices once synced.

Software
Apart from decoding software, iTunes comes with a suite of social networking and connectivity programs – such as Genius – which are integrated into its user interface. It also packs advanced media management software, automatically maintaining and organising a person's library with metadata tags and binary files. Various software plug-ins also allow non-Apple products to be synced with iTunes.

Links
iTunes also acts as a social networking hub, allowing artists and consumers to interact with each other and among themselves. In addition, as an aid for its users, iTunes supplies direct links to auxiliary websites with content-specific information, allowing them to learn more about a track, artist or application before making a purchase.

All images © Apple

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"The differences of each channel tricks the brain into thinking sound is coming from different directions"

How do wireless speakers work?

Discover the inner workings of a modern wireless speaker system, and find out how they output audio signals

Wireless speakers combine the same basic techniques that the first speakers and wireless devices were based upon. So what makes modern wireless speakers stand out? Well, today's systems employ a transmission protocol called SKAA – a hi-fi audio standard that uses a portable device as the sound source that can be connected to any wireless gadget with support. Today, the 2.4GHz radio wavelength is a very crowded frequency as it's such a high-quality audio band, so SKAA makes use of a patented protocol to avoid conflicts with any other devices.

Of course, speakers themselves have been refined in many ways over the years too. Alloy tweeters are now geometrically designed using computer software to find the optimum shape, then coated with ceramic and anodised with gold: this improves high-frequency sound output.

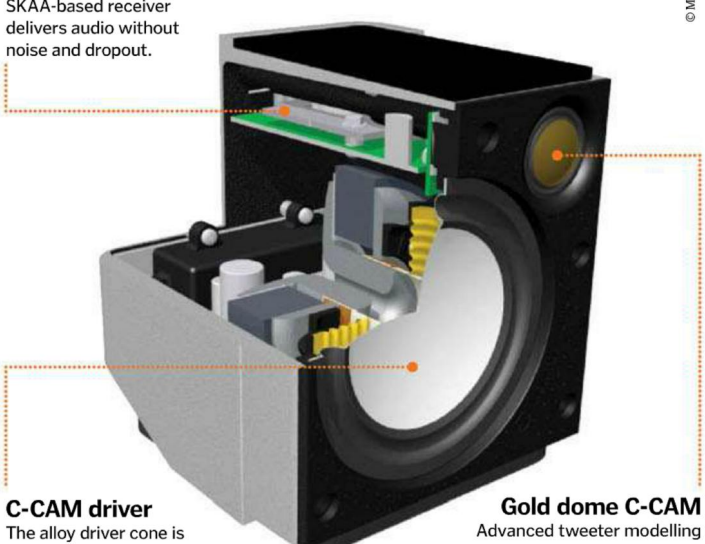
Elsewhere, the main drivers are made out of the same light yet rigid material that was originally developed for jet engines, which ensures it is highly resistant to flexion, or bending. This also significantly reduces audio distortion at higher audio outputs.

Explore the WS100

We examine a wireless speaker from the inside out



Wireless receiver
The core of the speaker's communications tech, the SKAA-based receiver delivers audio without noise and dropout.



© Monitor Audio

C-CAM driver
The alloy driver cone is coated with an ultra-thin (50-micrometre) layer of ceramic alumina to dissipate heat.

Gold dome C-CAM
Advanced tweeter modelling moves sound breakup beyond the 35kHz range for clarity that extends way beyond human hearing.



Sound fields
The combination and interaction of the speakers creates the illusion of a 3D audio environment.

Surround-sound headphones

How headphones reproduce three-dimensional audio in your ears

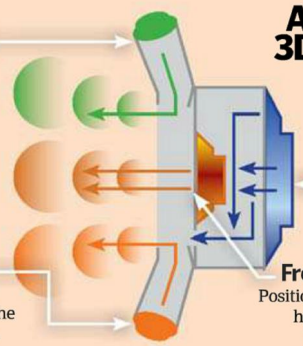
Each earpiece enclosure on a set of surround-sound headphones generally comprises three separate speakers. There is a central speaker that works just like that in normal headphones, and to either side of it are a centre-field speaker and a rear-surround speaker. A central sub-woofer driver, meanwhile, delivers low-frequency bass audio effects.

Such an arrangement corresponds to the commonly used 5.1 surround-sound system that utilises five 3-20,000 Hertz audio channels and a low-frequency 3-120 Hertz effects channel. The six channels individually supply the left and right-field speakers, the left and right surround speakers, the two centre speakers and the sub-woofer.

The differences in the volume and timing of each channel tricks the brain into thinking sound is coming from different directions/sources, which creates a convincing 3D audio landscape for the listener.

Anatomy of 3D surround sound

Centre-field speaker
Angled 90 degrees upwards from the central front-field speaker.



Sub-woofer
This delivers low-frequency bass sound.

Rear-field speaker
Angled 90 degrees downwards from the front-field speaker.

Front-field speaker
Positioned at the centre of the headset enclosure as per standard headphones.

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5 TOP FACTS EARLY CINEMA

1 Celluloid
In 1889, Eastman Kodak introduced celluloid, a transparent flexible film with a photosensitive emulsion. Reels of celluloid were essential for the creation of movies.

2 The cinematograph
Louis and Auguste Lumière patented their cinematograph apparatus in 1895. In the same year, they used it to show films to a paying audience at Le Grand Café in Paris.

3 Special effects
In 1896, showman Georges Méliès used the Theatre Robert-Houdin as the first public cinema. He played with special effects to make several fantasy and sci-fi films.

4 The Great Train Robbery
This 12-minute film, directed by Edwin Porter, used location shooting, camera movement, closeups, cross cutting, double exposures and editing to throw the viewer into the action.

5 The Birth Of A Nation
This DW Griffith film was an epic three-hour depiction of the US Civil War. It had an orchestral accompaniment, which added to its huge success. It was a forerunner of the 'blockbuster'.

DID YOU KNOW? *When Al Jolson prophetically said, "You ain't heard nothing yet," in The Jazz Singer, audiences stood and cheered*

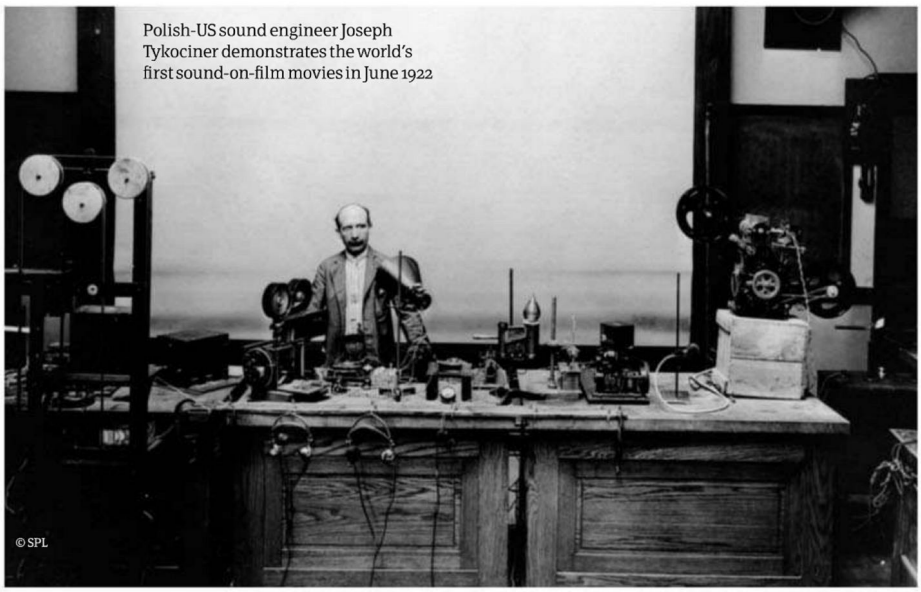
The first talking pictures

Discover the history of the technological race to introduce sound to the cinema

It took over 40 years for synchronised sound systems to be successfully introduced to cinemas, bringing audio to the movies. There were two major approaches to synchronising sound with films. One was to use gramophone discs to record and play back the sound, as demonstrated in the Vitaphone system (see below), while the other approach was to install the sound on an optical track alongside the images on the film itself.

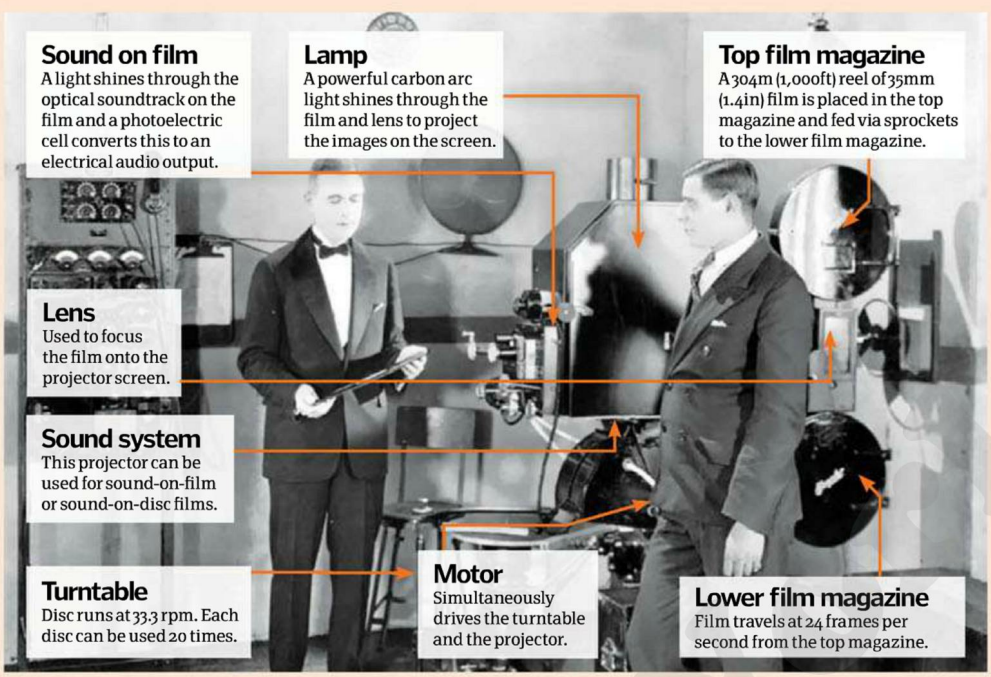
Sound-on-film evolved through a series of inventions. One significant patent in 1919 was for Tri-Ergon's variable density technology. This employed a flywheel mechanism that fed the film through the projector sprockets at a constant speed to prevent the sound on the film being distorted. Second, they used a photoelectric cell to convert electrical waves into light waves that could be recorded onto the edge of the film reel. The projector contained a photoelectric cell that converted the light waves back into electrical waves that were then amplified and played to the cinema audience.

At the same time Lee De Forest produced a similar Phonofilm system; however, to make it viable he had to use a gas-filled AEO light tube which, in response to an audio input, produced light waves that could be photographed. Theodore Case, the inventor of the AEO light, with his assistant Earl Sponable, developed this technology at the Case Research Laboratory to produce the Movietone system for the Fox Film Corporation. It was used to make Movietone News newsreels from between 1928 and 1939, and feature films until 1931.



Polish-US sound engineer Joseph Tykociner demonstrates the world's first sound-on-film movies in June 1922

"The projector contained a photoelectric cell that converted the light waves into electrical waves that were then amplified and played to the audience"



The Vitaphone system

Bell Laboratories and Western Electric, for the Warner Bros film studio, created the Vitaphone sound-on-disc system.

To stop the noise of its motor being picked up by the microphones positioned over or in the film set, the Vitaphone camera was housed in a soundproof booth. The sound was sent to a monitoring room where a technician balanced the sound levels before it was amplified and recorded on a wax disc.

The Vitaphone projector motor also drove a gramophone turntable. The projectionist cued a 'start' frame on the film and dropped the stylus on a marked groove on the 400-millimetre (16-inch)-diameter shellac disc. The projector motor was switched on, and the film and turntable simultaneously reached the proper running speed. Each disc ran for ten minutes corresponding with the running time of one reel of 35-millimetre (1.4-inch) film.

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"Instagram's services are delivered by over 25 64-bit computers with powerful processors"



Strobe lighting

How does strobe lighting generate such a bright dazzling light?

Unlike traditional incandescent lamps, which use electricity to heat up a metal filament until it glows white-hot over time, strobe lights specialise in generating a far more sudden and intense light source. They achieve this by storing a large quantity of energy in a capacitor, a battery-like device capable of being charged and releasing its charge incredibly quickly. Once the capacitor has been charged (usually around 300V), a small quantity of its energy is diverted through a trigger transformer into a light bulb/light tube filled with xenon gas. The transformer creates a high-voltage spike (2,000V) within its ferrite core that overcomes the resistance of the xenon gas within the bulb/tube, allowing ionisation. As the ionised gas offers a path of much lower resistance than the transformer, the capacitor then releases the remaining bulk of its energy into it, causing an instantaneous and dazzling plasma discharge. A strobe flash typically lasts around 200 microseconds.

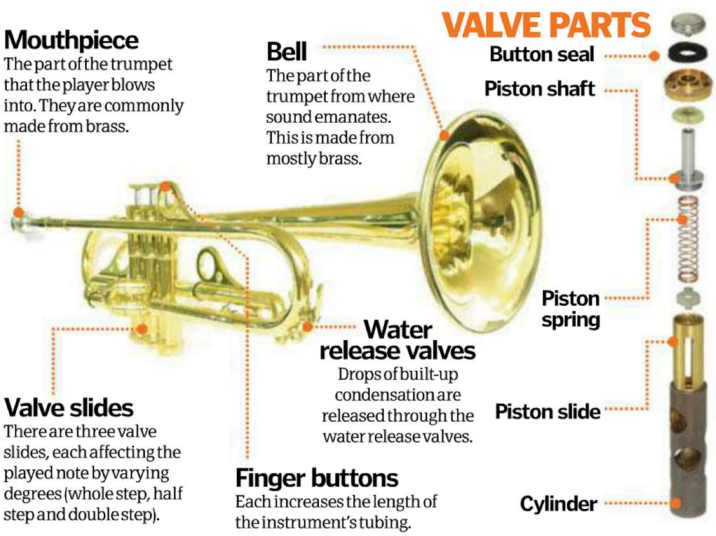
Trumpet technology

An ancient and versatile instrument, the trumpet is intricate in both form and function

The trumpet is an instrument in the brass family and, in its most basic form, is one of the oldest recorded in human history. A standard modern-day trumpet is constructed by wrapping cylindrical brass tubing twice over into a rounded oblong shape that tapers at both the mouthpiece and bell. The size and inclination of the tubing's taper determines the intonation, and can be purposely adjusted to create different types of trumpet and sound.

Produced tone and pitch is further modified by the addition of multiple valve slides and piston valves at the heart of the tubing. These achieve this by elongating or shortening the length air can travel, by blocking and/or re-routing it. Finally, the shape, depth and flare of the mouthpiece and bell also determine the sound.

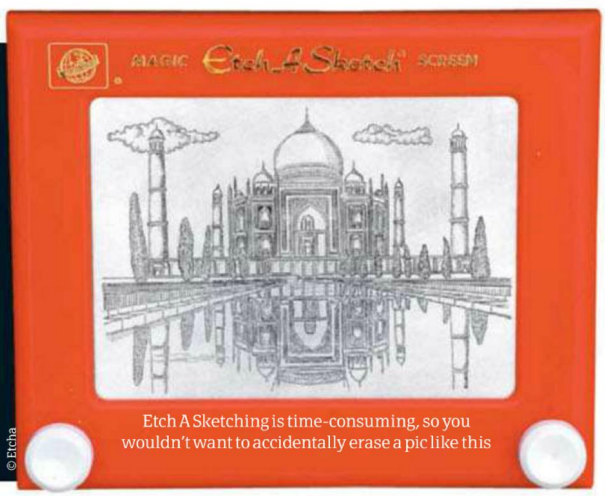
Trumpets are supplied with air from a player's mouth, which when varied in pressure and partnered with the mechanical modifiers, grant the instrument a broad playing range.



What's in an Etch A Sketch?

How does this mechanical drawing toy operate?

This popular child's toy works by encasing a clear glass or plastic screen within a plastic housing, that itself is filled with a large quantity of aluminium powder and tiny ball bearings. This powder sticks to the screen – evenly spaced by the ball bearings – and generates the greyed slate, upon which patterns can be drawn. The drawing mechanism is activated by two circular dials, positioned in the bottom-left and right corners of the plastic frame. These are attached to a stylus via a pair of orthogonal rails, which when turned cause the stylus to draw lines in the aluminium powder. This action, when viewed from outside the Etch A Sketch, appears as if black lines are being drawn on the grey slate. In fact, however, the stylus is merely exposing the darkened interior of the plastic casing to the human eye. Naturally, when the device is turned upside down or shaken, the aluminium powder recoats the clear screen, destroying the previous carved lines and presenting a clean slate.



Etch A Sketching is time-consuming, so you wouldn't want to accidentally erase a pic like this

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5 TOP FACTS TRUMPET HISTORY

Guarded
1 In medieval England, trumpet playing was a highly guarded craft, with instruction only occurring within prestigious guilds. When in a military troop, trumpeters were guarded.

Ancient
2 Basic trumpets have been excavated from ancient tombs. Locations include Egypt, Scandinavia and China. Depictions of trumpets have also been found in Peru.

Mouths
3 Orchestral players prefer wider, deeper mouthpieces, while jazz players favour narrower, shallower types. The shape and depth of the mouthpiece affects tone.

Valves
4 The valved trumpet appeared in Germany in the 1820s. Its adoption was delayed in the US and Britain due to players and guilds committed to the older cornet-type instrument.

Relegated
5 From the start of the classical music period in 1750, through to the end of the romantic period in 1910, the trumpet was largely relegated to a minor role in an ensemble.

Inside Instagram

Discover the tech behind the billion-dollar app that adds retro effects to your photos in seconds

Everybody knows that social-networking services thrive on constant interaction with a large and diverse community of users. The smartphone-based photo-sharing app Instagram has taken only two years to master this, securing over 50 million snappers worldwide and a highly publicised $1 billion (£638 million) takeover by Facebook.

Ironically, given its value according to Facebook, Instagram runs on a version of the free Linux operating system Ubuntu. Free doesn't mean limited though: Instagram's services are delivered by over 25 64-bit computers with powerful processors, each connected to the same server infrastructure that supports Amazon's websites.

Day and night these computers manage the mass of descriptive information, or metadata, in user profiles and photos using another piece of free software called PostgreSQL. This database system gives Instagram users on-demand access to specific data, such as photo locations, using keywords and hashtags.

At the frontend, the Instagram app allows uploaded photographs to be modified using filters that produce effects such as converting colour to black and white or boosting contrast. When a user picks a filter, Instagram runs a mini-program called a script. This employs mathematical algorithms that determine which colours the pixels in a picture should be to create the desired result.

Instagram can even expand beyond the app thanks to its application programming interface (API). The API is essentially a software socket that allows third-party programs to plug in to core information including image metadata and tags. The results include cool extensions like This is Now (http://now.jit.su), a website delivering real-time feeds of Instagram photos from major cities around the world.

Instagram filters produce a number of different effects, from giving a photo a focal point to adding depth of field or aesthetically ageing a shot





Key features behind the app



Filters
Every detail in a photo is determined by the colour of its pixels. When a filter is applied, a software script changes these where necessary to achieve the desired finish, eg Lo-Fi.

Metadata
If you write a caption for a photo, it's saved as part of the image's metadata – coded information that includes the time and location of where the picture was captured.

Search
When looking for friends to add to your Instagram network, the app sends a query to the service's massive database, which is stored across a series of powerful servers.

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"They will hear the roar of the crowd shortly before they see the triumphant event on their TV"

Broadcasting live sports events

Much like any live performance, the secret to a successful live sports broadcast is preparation

Long before the sportspeople enter a venue, the broadcasting crews have set up, tested, rehearsed and – just to be sure – rehearsed again.

The entire broadcast team practises with a run-through. During the broadcast, the output picture must look coherent whenever the vision mixer switches from camera to camera. To match the pictures, the vision engineer runs a 'lineup' before the event – all the cameras point at a greyscale chart and are adjusted for white balance and exposure.

Everything is prepared and pre-set well in advance so the camera operators can concentrate on moving, composing, focusing and zooming. Everything else is controlled remotely. The expensive professional cameras are fixed to tripods or trolleys, or handheld using a stabilisation rig like 'Steadicam'. With the director orchestrating the team via headsets, the cam ops' experience will greatly dictate the results.

In the mobile broadcast truck, or location studio, the director, vision mixer and graphics editor co-ordinate the output. In a separate area, the sound team prepare and mix the audio. They usually work in a well-insulated booth so they can accurately monitor the sound, without interference.

Many sports events use infographics to display team info, match data and so on. These are all pre-set and co-ordinated with the official results system at the venue. On the monitor, a camera operator can check a composition fits with the graphics by viewing the output as either 'clean' or 'dirty': clean is the picture by itself, while dirty is the picture plus any graphics.

But what happens if there's a problem, such as a camera failing, a race being delayed, or a more serious situation such as a terrorist attack? Commercial channels can switch to an advert break. For non-commercial channels like the BBC, this is when the skill of the presenters is tested as they talk to 'fill in' while the situation is resolved. This will have been rehearsed and there may be a piece of emergency video standing by just in case it's needed.

How 'live' is live? As anyone who lives near a stadium or similar venue will tell you, the delay for a true live broadcast is just a few seconds: they will hear the roar of the crowd just shortly before they see the triumphant event on their television. Some 'live' TV shows build in a longer delay, from a few extra seconds up to 15 minutes so they can broadcast events which occur simultaneously – getting a chance to remove bad language, for instance, in this interim period.



© BrokenSphere 2008

Outside broadcast vans enable broadcasters to transmit footage from almost any location away from the studio

Anatomy of a Steadicam

A full professional Steadicam rig like this can cost up to £40,000...



Vest
This helps distribute weight around the operator's body. The work is physically demanding and ideally operators should be 1.8m (6ft) tall, so it's rare to see women operating Steadicams for long periods.

Spring-loaded arm
This smooths the forward and backward movement.

Operator
The operator stands with bent knees for optimum stability and balance, ready to move quickly but steadily.

Handles
To move the camera smoothly up and down, as well as left and right.

Batteries
Large cells store hours of charge so the operator isn't tethered by power cables. The monitor and batteries also act as a counterweight to the bulky camera sitting on top of the rig.

© Courtesy of Broadcast RF

Live TV transmission step-by-step

To deliver crystal-sharp

Step 1
Professional camera
Operated by a human or by remote control. Camera operators have a headset for communicating with the director and a cue light to indicate their footage is the picture being broadcast. Cameras are set up in advance by assistants. Operators may pepper their focus and zoom controls with markers made from tiny triangles of electrical tape so they can quickly move to rehearsed settings.

Step 2
Link to CCU
The data from the camera's processor is sent to the camera control unit (CCU). For live sports, broadcasters often use wireless microwave links. If the camera is connected via cables, HD signals are sent down fibre cables, while SD signals are sent via triax cables. Many venues have 'tie-lines' – fixed points built in to the venue's infrastructure so cables can be plugged in and data sent to the CCU.

Step 3
Camera control unit (CCU)
This is effectively the 'brain' of the camera. Vision engineers monitor the live picture and 'ride the levels' continuously to make sure the white balance and exposure is set correctly for all the cameras. The engineers transmit requests to the CCU by remote control, which in turn alter the camera settings.

Step 4
Digital interface
Data from the cameras is processed at a digital interface, which transforms it into robust signals that can then be transmitted over large distances without losing any of the quality.



Right: An operator's view of a fixed camera

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KEY DATES
TV BROADCASTING

1924-1925 John Logie Baird invents and demonstrates live TV broadcasting.

1936 The Olympics in Germany is the first live sports transmission (right), transmitted by cable and viewed in Berlin and Leipzig.



© Telefunken-Bild, Berlin

1966 At the FIFA World Cup in England, 32.3 million watch the world's first live sports broadcast in colour.

1975 The UK's first live sports broadcast from abroad is Ali and Frazier's 'Thrilla in Manila' fight.

2006 The FIFA World Cup in Germany is the world's first live sports event broadcast in HD.

2010 Sky broadcasts a football match between Arsenal and Manchester United live in 3D to nine pubs in the UK.

DID YOU KNOW? *When London hosts the 2012 Games, the BBC will broadcast around 2,500 hours of live TV*



Microwave receiver
Receives commands from the camera control unit (CCU) to adjust settings on the camera, and receives the video feed of the live output.

Microwave transmitter
This sends data from the camera's three CCD chips to the camera control unit.

Microphone
The furry cover minimises noise generated by wind.

Camera
The operator will have pre-set options on this professional camera so that they can respond quickly.

Monitor
Shows either the image captured by the camera or the live output. The operator needs to use a monitor because they can't look through the viewfinder and professional cameras don't usually have an LCD screen.

Pro vs consumer cameras

Lenses

- Consumer cams have a built-in lens whereas pro cams have interchangeable lenses (wide-angle, telephoto, etc). For filming drama, cameras may use fixed focal-length lenses because the action is controlled; for unpredictable sports events, meanwhile, cam ops select lenses that allow them to respond to varying conditions.
- Pro lenses are larger and more expensive because they're precision-made from thick, scratch-resistant glass assembled in a dust-free environment.

Zoom

- Consumer cams usually measure zoom as 4x, 8x and so on, because it's easier to understand.
- Pro cameras, in contrast, have stronger and more precise zoom lenses, measured in millimetres.

Chip

- Consumer cams often have just one CCD (charge-coupled device): the silicon chip which converts light to digital signals.
- A professional camera will have a minimum of three CCDs – one each for red, blue and green light. This extra information means a clearer picture capable of good resolution at larger sizes. Some pro cams use CMOS (complementary metal-oxide semiconductor) chips, another method of capturing data which requires less off-chip circuitry to process the data than a CCD.

Presets

- Consumer cams don't usually have the option to create their own presets for different conditions.
- Pro cams allow the operator to construct and save settings for different conditions, which in the future can be accessed at the touch of a button.

Versatility

- Consumer cams usually have just one method of recording, while pro cams are adjustable.
- Professional cameras can record in PAL (UK format, 25 frames per second) or NTSC (USA format, 30 frames per second); all the settings can be manually varied and the data-rate can be altered too. Pro cams can produce super-clear slow-motion playback with a frame rate of 50 fps, or even 100 fps.

HD and 3D

- These new developments require cameras to capture more information. Standard definition (SD; ie 704 x 480 pixels) has now been replaced by high definition (ie 1,920 x 1,080 pixels) in all pro cams and most consumer cams. You need an HD-compatible television or computer in order to play HD video, otherwise it's compressed to SD.
- Pro cams are now available with a super-high definition of over 4,000 pixels. Why bother with these new formats? They are especially good for sports viewing – the extra-fine resolution of HD means viewers can identify fast-moving players in wide shots, and 3D images communicate every detail of the action such as the distance between finishers in a sprint or the length of a javelin throw.

video to your TV, broadcasters use a complex array of technology

Step 5
Mobile broadcast van, or location studio, featuring:

Director Orchestrates the output – instructs the camera operators via their headsets and decides which camera picture to broadcast.

Vision mixer Follows director's instructions on what to focus on and image treatment, etc.

Sound editor The sound editor mixes audio 'on the ground' and from commentators.

Graphics Pre-set graphics are co-ordinated with the venue's results system and added to the output picture before transmission.

Step 6
Output sent
The sound, camera pictures and graphics are sent via cable to the 'sat truck' (for an outside broadcast) or master control room (if the directing gallery is in a studio). The signal is then sent to the broadcaster's transmission control centre, often via satellite but increasingly via a super-fast, high-quality internet connection.

Step 7
Live transmission
The broadcaster's transmitter sends the signal by electromagnetic wave to transmitters across the country (and via satellite to the rest of the world). The transmitters then broadcast the signal to homes.

Step 8
Watched by viewers
The digital signals are received at the viewer's aerial, then decoded and played by a TV so the viewer can enjoy the event, often with a better view than the audience at the venue. For a true 'live' broadcast, the delay will be just a few seconds.

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Ultra-slim OLED screens

Revealing the amazing technology that allows the latest TV displays to be so incredibly thin. Find out how everything fits into such a small space

Most mid-range TVs and computer monitors today are called LED displays, but this is an inaccurate shorthand. The LED, or light-emitting diode, is just the light source. An array of LEDs sits behind the picture, or around the edges with special diffusers, to illuminate the image. The pixels themselves are still generated by an old-fashioned liquid crystal display (LCD). This is because traditional semiconductor LEDs are much too big to work as individual screen pixels in an average TV.

Organic LED (OLED) technology is different. The organic chemicals that generate the light can be produced in very thin films. So thin, in fact, that they can actually be printed into the screen matrix using a machine like an inkjet printer – except that it prints pixels instead of ink dots. The limitation on how small you can make the pixels depends not on the size of the OLEDs themselves, but on how tightly you can pack together the grid of transistors to switch them on and off. This is the same grid that LCD screens use, so the manufacturing process already exists. OLED screens have the same pixel resolution as LCDs, however they are drastically thinner. Not only are the OLED pixels themselves thinner, but you don't need to allow room for a backlight; the OLEDs are their own light source.

These two factors mean that OLED screens are up to a third of the thickness of today's slimmest TVs. Early OLED displays suffered from relatively short life spans – especially in the blue pixels – but new organic molecules that produce brighter, truer colours and last far longer are being developed. As far as TVs go, the future isn't just bright – it's ultra-thin too.

An organic diet

How do organic LEDs manage to be so much thinner than other displays?



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1. THIN

Sony KDL-40NX713

One of the thinnest of the current generation of LED backlit screens, this Sony TV is just 32 millimetres (1.3 inches) deep.



2. THINNER

Samsung ES9500

Samsung's debut 140-centimetre (55-inch) OLED screen has a razor-thin profile of 7.6 millimetres (0.3 inches).



3. THINNEST

LG EM970V

LG wins with a screen just four millimetres (0.2 inches) deep. Both this and the Samsung ES9500 will be on sale at some point in 2013.

DID YOU KNOW? *OLED screens can display up to 100,000 fps, compared with 60-480 fps for LCD displays*



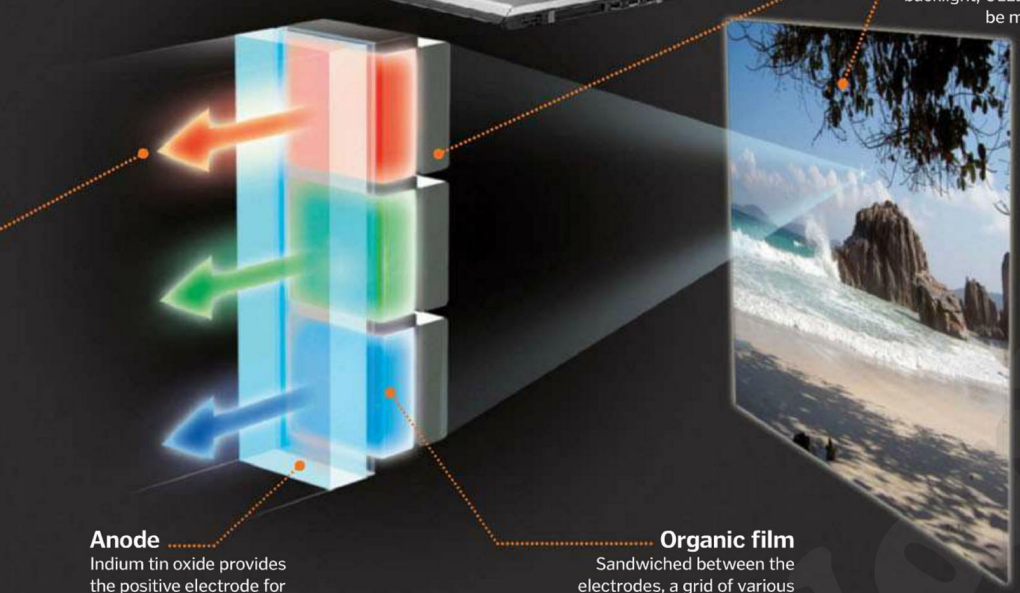
LG's EM970V is currently the world's largest and slimmest OLED television

Thinner and twistier

Most OLED displays are made by depositing the different layers on a sheet of glass that forms the front of the screen. But if you swap the glass for a plastic, like PET, you can make OLED screens that are even thinner, and flexible enough to wrap around a pencil. It's a bit more complicated than that, obviously, because the electronics that control the OLED pixels have to be flexible as well. The organic molecules themselves also degrade when exposed to air and moisture so a flexible screen must be very tightly sealed. Nevertheless flexible screen technology opens up the possibility of manufacturing displays in a continuous roll, with the components 'printed' directly onto the plastic like an inkjet printer. And soon, quantum-dot (QD) displays – which use nanocrystals of cadmium selenide instead of organic polymers – will make it even easier to print the thinnest, most flexible displays yet.

Switching layer
Active matrix screens have a grid of transistors located directly behind the OLEDs to turn them on and off.

Ultra-thin
Without a bulky vacuum layer or a separate backlight, OLED screens can be much slimmer.



Anode
Indium tin oxide provides the positive electrode for the OLED. It's transparent so it can go at the front.

Organic film
Sandwiched between the electrodes, a grid of various organic compounds serves as the light-emitting layer.

TV tech translated

Cathode ray tube (CRT)
Old-style TVs use a heavy glass vacuum tube chamber. Electrons are generated at one end by heating a metal filament – just like a light bulb. Electromagnets accelerate and steer the beam of electrons (cathode rays) so that they strike a grid of phosphor dots which causes them to glow.

Liquid crystal display (LCD)
Liquid crystals change the polarisation of light passing through them. Pixels are activated or deactivated by rotating the liquid crystal molecules with an electric field. A polaroid filter at the front blocks out all the light shining through the pixels, except the ones that have been rotated correctly.

Organic light-emitting diode (OLED)
Certain organic compounds and polymers will emit light when you run an electric current through them. Sandwiching a layer of this compound between two electrodes enables you to turn them on and off. Different materials illuminate in different colours.

Plasma display panel (PDP)
Each pixel is essentially a tiny fluorescent light bulb. A low-pressure mixture of xenon and neon gases is ionised to a plasma by an electric field and the colliding gas atoms emit a small amount of ultraviolet light. This strikes a fluorescent coating at the front to convert the UV into visible light.

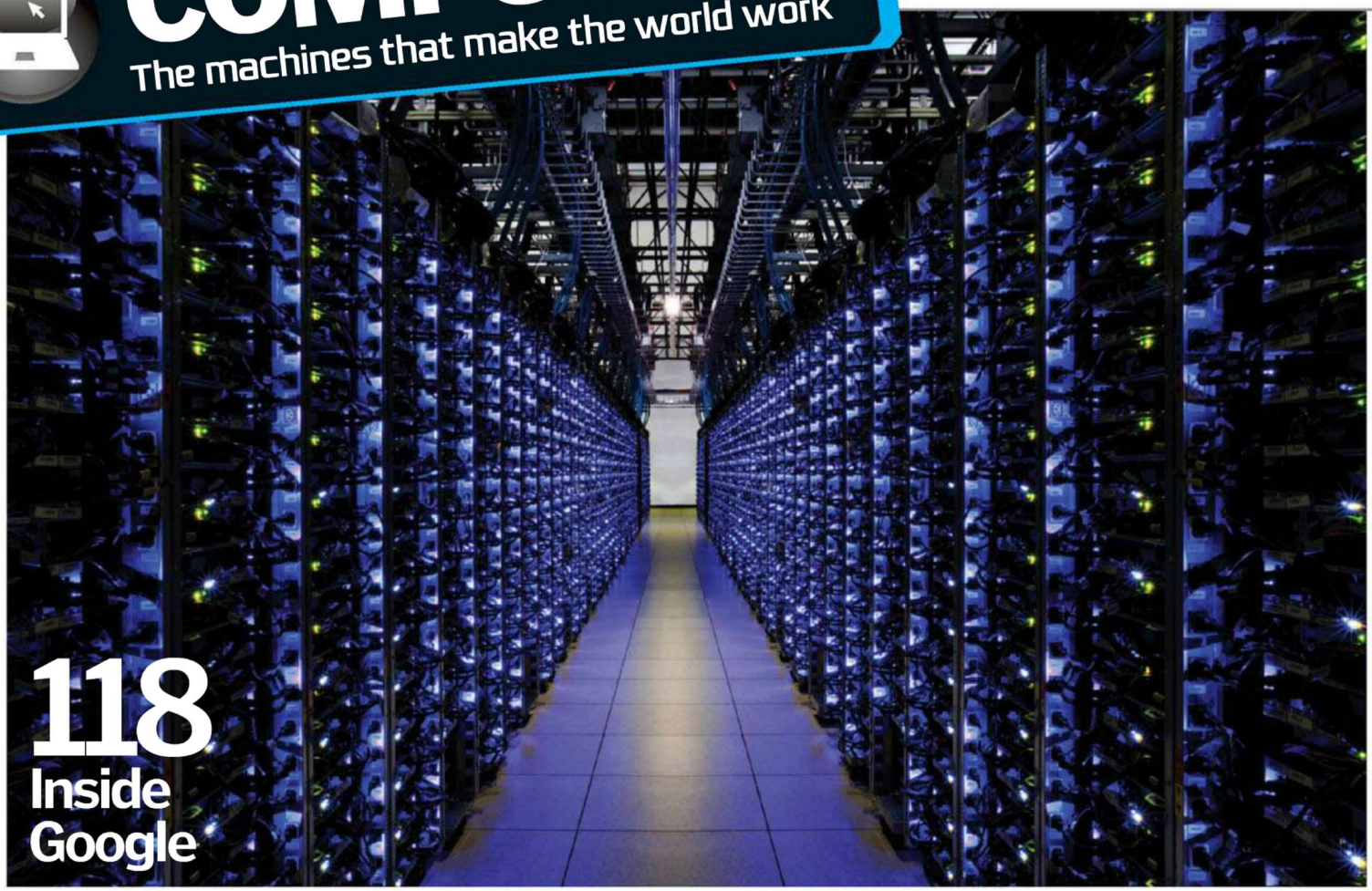
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HOW IT WORKS

COMPUTING

The machines that make the world work



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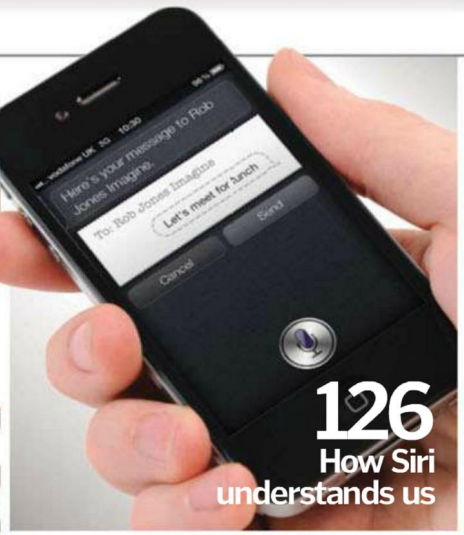
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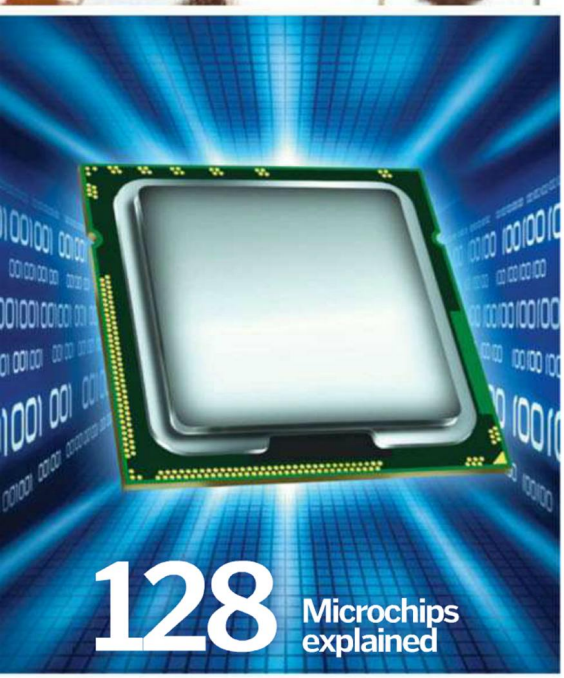




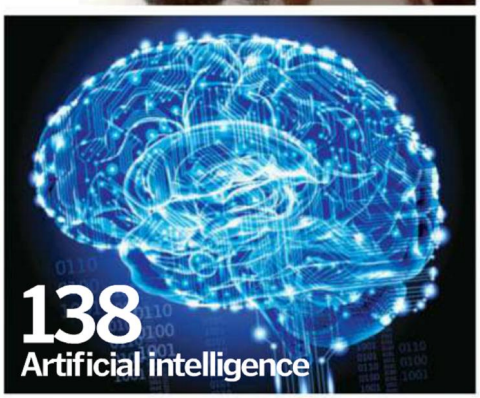
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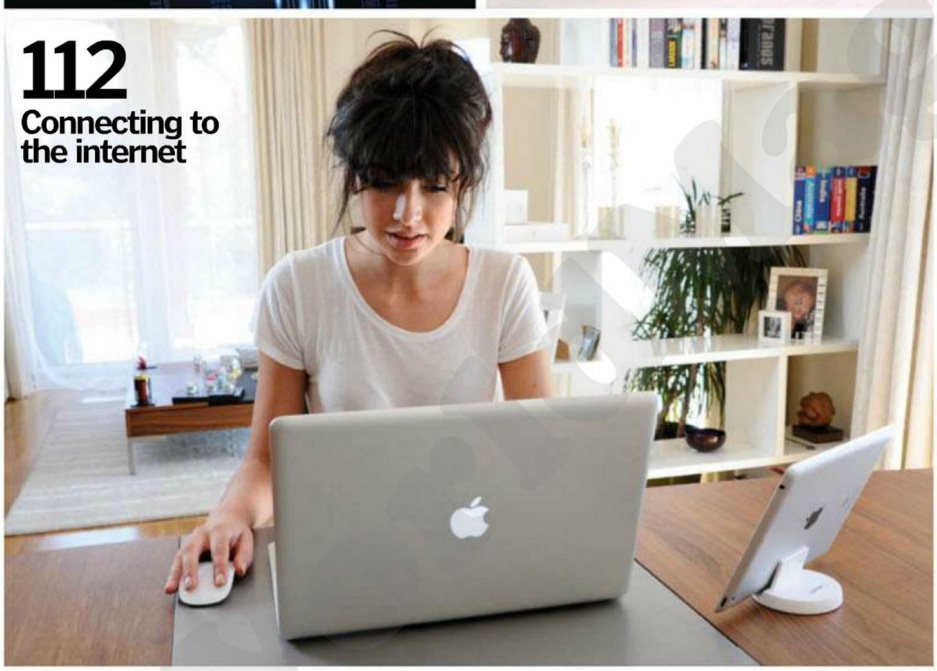
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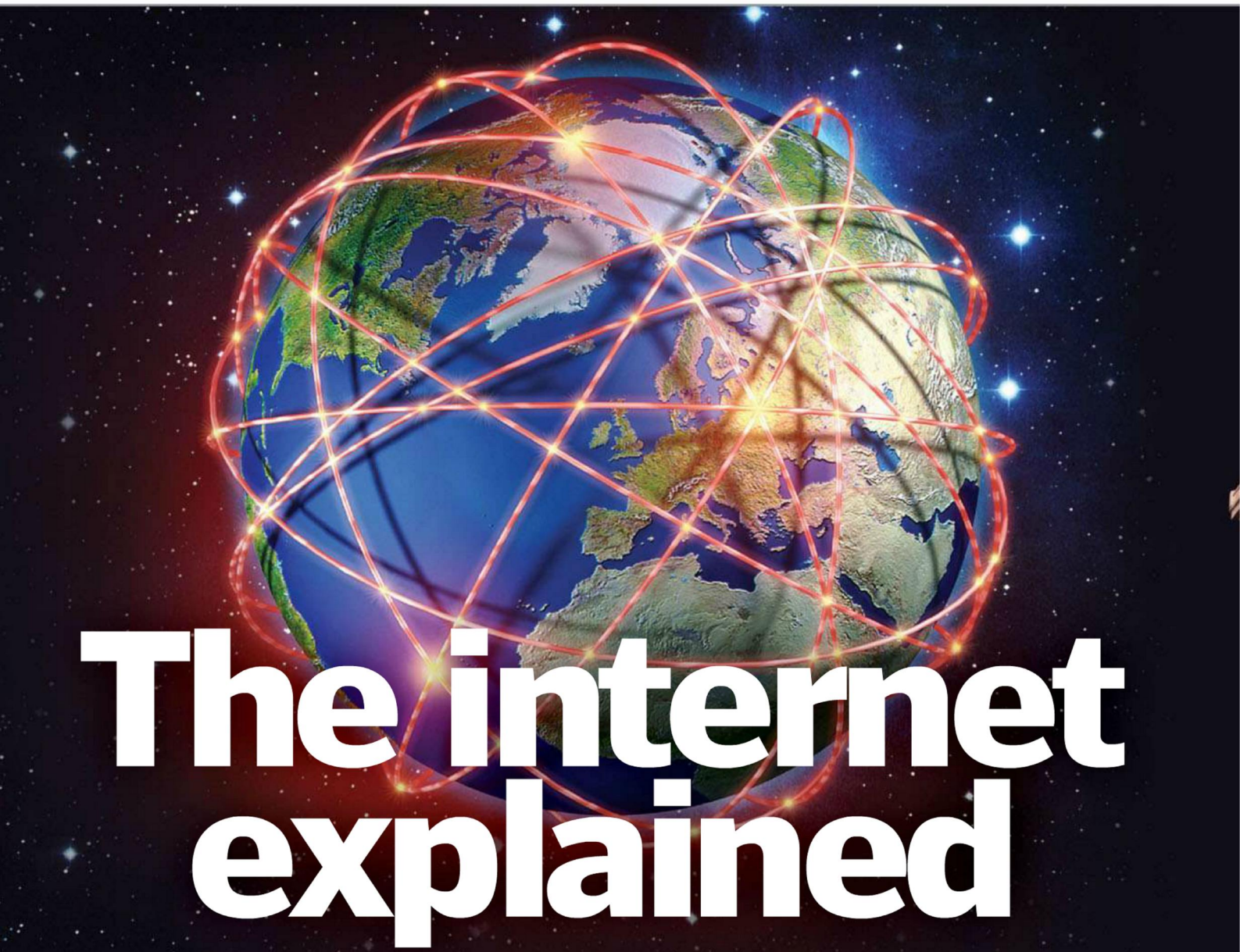
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"The internet has the ability to subvert national laws and overthrow governments"



The internet explained

It takes more than just cables to connect over 2 billion people and six continents

23 years ago, you had never looked at a webpage, 16 years ago you hadn't searched on Google. Just nine years ago you had yet to see a YouTube video. All these things are now as much a part of our lives as television, and much more relevant to most of us than newspapers. The internet has the ability to subvert national laws, overthrow governments – and even find us a husband or wife.

But what actually *is* the internet? Like gravity, it's so ubiquitous we mostly just think of it as a sort of magic glue that binds us. The server that hosts **www.howitworksdaily.com** isn't strictly *part of* the internet, it's *connected to* the internet. The internet itself is the collection of links that join the smaller networks run by companies, governments and other organisations. It's a network of networks.

When you type **www.apple.com** into your browser address bar, the request for that webpage travels from your computer to your broadband router by Wi-Fi radio signals, but after that, its journey is constrained by wires. First it travels through ordinary telephone wires to your local telephone exchange. Then it gets routed through higher-capacity lines that connect to your Internet Service Provider (ISP). For convenience, these cables follow the same route as the voice telephone lines and share the same trenches in the ground, but they are dedicated data cables that only carry digital internet traffic. Your ISP has leased capacity on even bigger fibre-optic cables that forward your data to one of the major internet exchanges, such as the London Internet Exchange (LINX).

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KEY DATES INTERNET HISTORY

1969
ARPANET, precursor to the internet, is created. The first message was the L and O of 'login'.



1982
The 'smiley' emoticon (left) is invented in 1982, by a professor at Carnegie Mellon University, PA, USA.

1985
The first .com domain name is registered. It was **symbolics.com** and belonged to a Massachusetts computer firm.

1996
Hotmail launches the first free web-based email service. Microsoft buys it for $400m the following year.



2004
Mark Zuckerberg launches Facebook, which hugely popularises social networking.

DID YOU KNOW? *The first webcam was set up in 1991 in a lab at Cambridge University. It showed a coffee pot*

Bridging the ocean

Faster, cheaper and with a higher capacity than satellite links, submarine cables carry 99 per cent of transatlantic traffic

Stateside
Transatlantic cables come ashore in New York state or New Jersey. This allows the fastest connection to the financial centres in New York.

Off the hook
There are at least 11 cable systems, owned by different consortia. The mid-ocean is too deep for fishing so cables are safe to lie on the seabed.

Inside a submarine cable

Stranded steel wires
Armour plating to resist damage from rocks, anchors and even shark bites!

Copper tube
Carries electricity to power the repeater units attached to the cable at regular intervals.

Optical fibres
No thicker than a hair, each can carry 10,000 times more data than a broadband connection.

Petroleum jelly
Vaseline acts as a shock absorber for the delicate glass fibres in the middle.

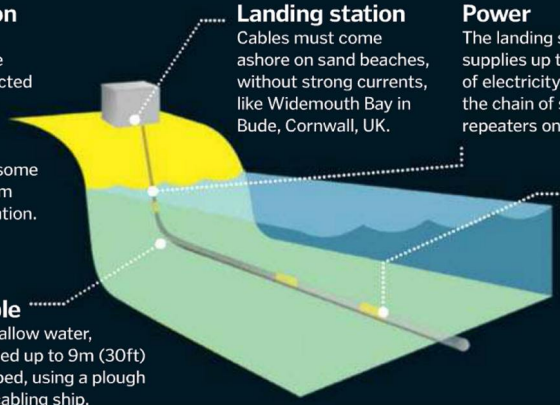
Polycarbonate
An insulating sheath formed from the same plastic used for CDs.

Aluminium
This tube offers a waterproof coating that won't crack, even when very cold.

Mylar tape
Helps to hold the steel wires in place.

Polythene outer sheath
This is normally formed from braided polythene cord that is wrapped around the cable to cushion it from scrapes.

How does a submarine cable carry data between the land networks?



Termination station
The submarine cable is connected to the land network at a termination station, often some way inland from the landing station.

Landing station
Cables must come ashore on sand beaches, without strong currents, like Widemouth Bay in Bude, Cornwall, UK.

Power
The landing station supplies up to 4,000V of electricity, to power the chain of signal repeaters on the cable.

Repeaters
To boost signal strength and clarity, laser repeaters are positioned every 60-100km (37-62mi) or so along the cable.

Buried cable
In relatively shallow water, cables are buried up to 9m (30ft) below the seabed, using a plough towed by the cabling ship.

Exit point
Most of Britain's transatlantic cables leave from Bude or Dartmouth in the south. Some have redundant pairs that originate from France.

This is a collection of ten buildings, in and around the Greenwich area, that are all joined together by multiple ten-gigabit fibre-optic lines. LINX is a non-profit switching centre whose running costs are shared by lots of ISPs to route traffic all over the planet.

To get to America, your webpage request must cross the Atlantic via a submarine cable. There are 11 main cable systems, leaving from either Devon/Cornwall, Ireland or France. Your data is passed to one of these by LINX, passing through a shorter submarine link under the English Channel or the Irish Sea, if necessary. The 5,650-kilometre (3,500-mile) journey over the pond takes less than 100 milliseconds.

Back on land, more high-speed cables (sometimes called the internet 'backbone') take your request to a data centre. These are warehouses the size of shopping malls containing hundreds of rows of server cabinets. Apple has one of its main data centres in Maiden, North Carolina. The advantage of siting it there is because a data centre needs three things in large amounts: space, electricity and cooling. Cooler locations like North Carolina save a lot of power by using the natural cold air instead of air conditioning. Even so the electricity demands of all those servers is enormous. Over 1.8 trillion gigabytes was added to global data centre storage capacity in 2011 and all that data needs power to keep it accessible. Most data centre servers spend a lot of time idling, but extra capacity is needed to cope with sudden spikes in demand.

When your website request finally arrives at one of Apple's servers, the data for the front page is assembled, split into 'packets', each with the internet address of your home computer and then sent back the way it came. This happens every time you click a link.

© Corbis: Guillaume Paumier

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The internet in numbers

...from the fastest broadband to how many tweets we post each day

How long are we online?

How many hours do Britons spend online compared with the rest of the world?



Global rank	Country	Hours/month
1	Canada	43.5
2	USA	35.3
3	UK	32.3
5	France	26.6
11	India	11.9



294 billion

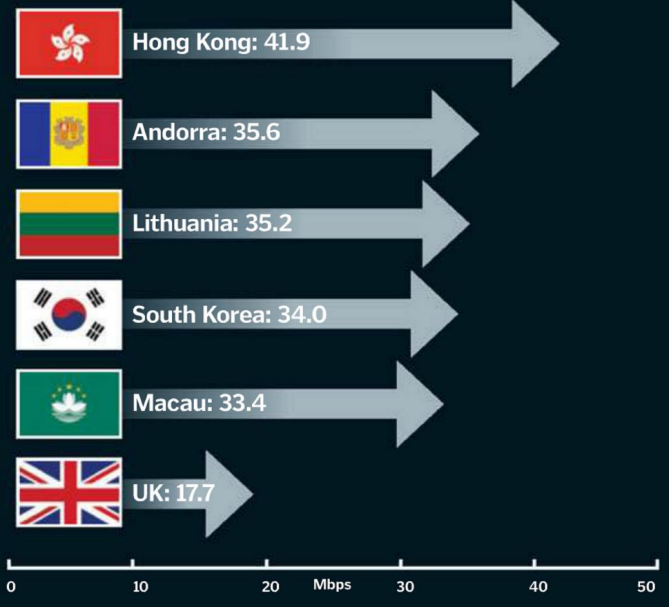
emails are sent each day worldwide

...compared with an estimated 3.5 billion physical letters and parcels



Who has the fastest broadband?

It may come as a surprise, but the fastest download speeds aren't from the biggest countries



1.63 billion GB

Data sent around the internet every day



This is equivalent to 347 million DVDs

WWW

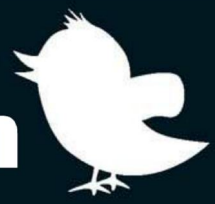
620 million

Number of websites worldwide

233 million

Total domains worldwide

250 million



tweets are sent every day

72 hours

YouTube

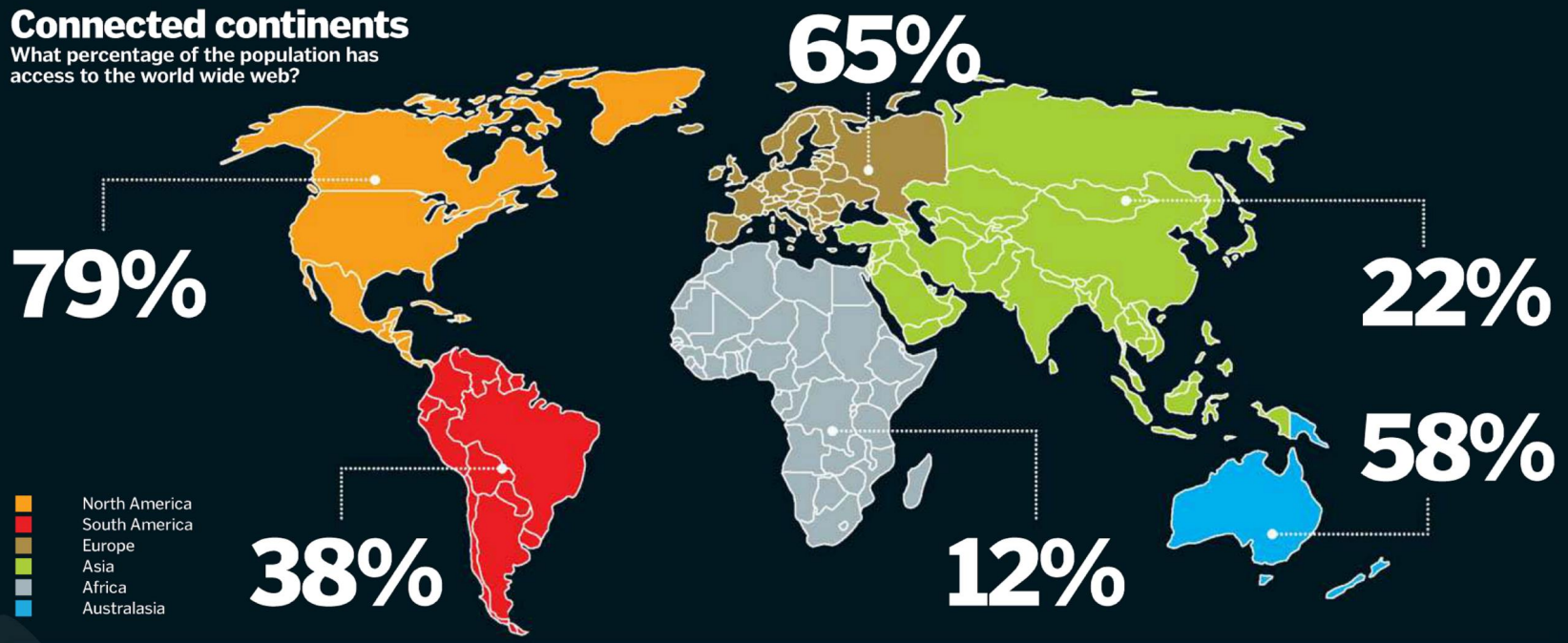
of video is uploaded to YouTube every minute

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"The internet itself is the collection of links that join the smaller networks run by organisations"

Connected continents

What percentage of the population has access to the world wide web?



Focus on social networks

Whether it's viral videos or pictures of our lunch, we're addicted to sharing



56% of users admit to spying on their partners through social networks



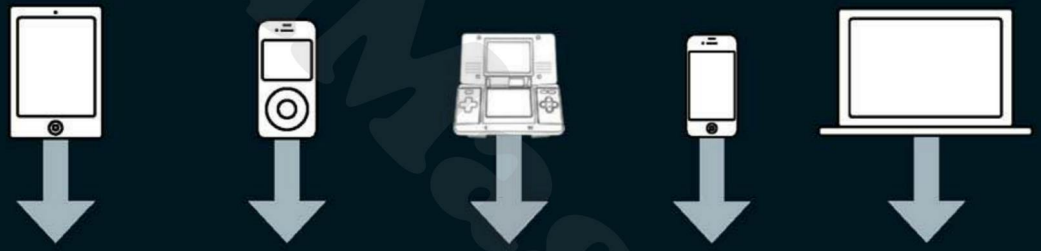
7hrs 46m Ave time a user spends on Facebook per month



Brazilians have the most online friends – an average of 481 per user

What are we surfing on?

What percentage of UK adults connect to the internet on each device?



Tablet computer (eg iPad): 6%

Portable media player (eg iPod): 8%

Games console (eg Xbox Live): 11%

Mobile phone: 45%

PC or laptop: 72%

Online activity breakdown

Discover how much time people dedicate to a range of tasks from shopping to emails



Social networking	22%
Searching	21%
Reading	20%
Emails/communication	19%
Multimedia	13%
Shopping	5%

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"If your video-conference hits a slow patch, it's better if the network discards any late packets"

The software of the internet

The internet is made of protocols... but what is a protocol?

The internet is like a road network. It consists of the tarmac and the junctions and the vehicles that use them. It also comprises the rules that govern how cars should travel. Rules like 'Stop when the light is red' are every bit as vital to the functioning of the internet as a real road system.

The main protocol is called simply Internet Protocol (IP). It defines the way data is broken into chunks, or packets, and each packet has the destination address marked separately on it. This means that if the stream of data gets interrupted en route – perhaps because one server gets too busy – the packets can be diverted to alternative links without losing their way. The packets are also numbered, so that the data can be reassembled in the correct order.

This fault tolerance works fine for most kinds of data. Webpages are fairly small, so you can wait for a second or two while the packets all arrive, and with video you can buffer a few seconds' worth to smooth out any hiccups in delivery. But games and video chat need a real-time exchange. They use a stripped-down version of the IP packet, called UDP (Universal Datagram Protocol) that misses out some of the fault-tolerant features of IP. If your video-conference hits a slow patch, it's actually better if the network discards any late packets and lets the image break up a bit, rather than stalling the whole conversation.

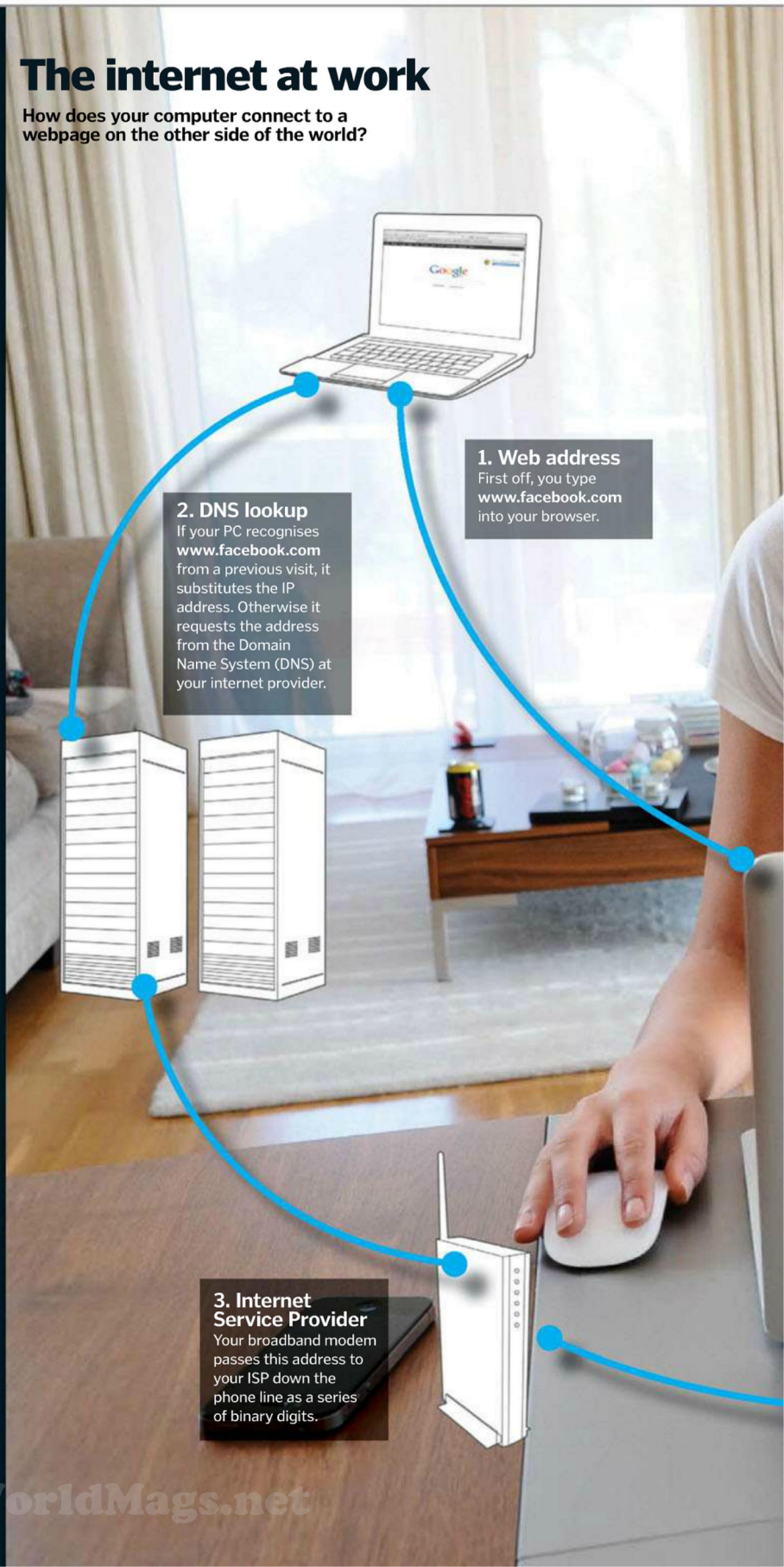
ISPs also prioritise some kinds of data over others. This is called traffic shaping and it enables them to ensure that time-sensitive data, such as video, doesn't get interrupted unnecessarily. Traffic shaping has a commercial side too. For instance, ISPs regularly prioritise web and email traffic for business customers over domestic online gaming.

An IP address is a sequence of four numbers – 65.55.58.201 is one of Microsoft's servers, for example. But number sequences are hard for humans to remember, so a separate Domain Name System (DNS) acts as an alias for all the IP addresses. When you register **myfirstdomainname.com**, an entry is made in a database that assigns an IP address to that domain name, so no one else can use it.

The original world wide web, designed by Tim Berners-Lee, used very simple webpages described by HyperText Markup Language (HTML). This leaves almost all decisions about layout and font to the web browser on your computer. Modern web designers want a lot more control over the layout so webpages nowadays don't use as much HTML. Instead, programming languages like Java create animated and interactive elements and the content is often generated dynamically by a database. This is what allows Gmail to show a personalised email inbox, for example.

The internet at work

How does your computer connect to a webpage on the other side of the world?



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5 TOP FACTS
INTERNET MYTHS

1 Nuclear attack proof
The internet protocol was designed to be highly fault tolerant. But that's because early network hardware was very unreliable – not because of the threat of nuclear war.

2 Berners-Lee made links
He invented the world wide web and the first browser program, but the hyperlink was invented by Ted Nelson as part of Project Xanadu at Harvard, 30 years earlier.

3 Social networks are new
In the Eighties, CompuServe, FidoNet and CIX bulletin board systems already allowed users on dial-up modems to chat online, leave messages and contribute to discussions.

4 Addresses are scarce
The IPv4 protocol only allows 4 billion unique addresses, but IPv6 is already rolling out and this will provide 10,000 trillion trillion addresses for every person on Earth!

5 The internet is free
It isn't and never has been. The internet is a very expensive collection of hardware paid for by governments, corporations and, ultimately, all of us.

DID YOU KNOW? *The first ever web address didn't begin with www but the slightly less catchy nxoco1.cern.ch*



The internet is *not* the web

The web is a collection of webpages, hosted on servers around the world and connected by links. The web uses the internet to transfer data between you and those servers, but it's just one of many services using the internet. Email is another one, so are the iTunes Music Store and the online game *World Of Warcraft*. The world wide web has only existed since 1991, but the internet was connecting universities, libraries and governments for 20 years before that. It's like saying a coach company, like Greyhound, is the same thing as the motorway.

The future?

The internet began as an academic network funded by the US Department of Defense. Today it is a transnational entity that consistently resists attempts to regulate or police it. Censorship and libel laws are circumvented with the same efficiency that allows internet traffic to reroute around physical damage to the network. The internet has jumped from the mainframe computer to the home PC, to the wireless laptop and then to the truly mobile smartphone. Google is already trialling the next major leap with Project Glass, which is a voice-controlled, internet-connected pair of glasses that projects information directly onto your retinas. Smaller, more mobile internet access devices could spell the end of the browser as our gateway to the internet. Indeed, webpages might be replaced by specialised apps that provide their own ways to share information; Facebook and Twitter already do this. Augmented reality, where information is overlaid on camera images and real-time maps, means that the internet is no longer just a place we visit. It's actually where we live.

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"Data centres have grown in proportion with the expansion of the internet in the last 20 years"

A look inside Google

What kind of equipment does the internet giant Google use to link up the world?

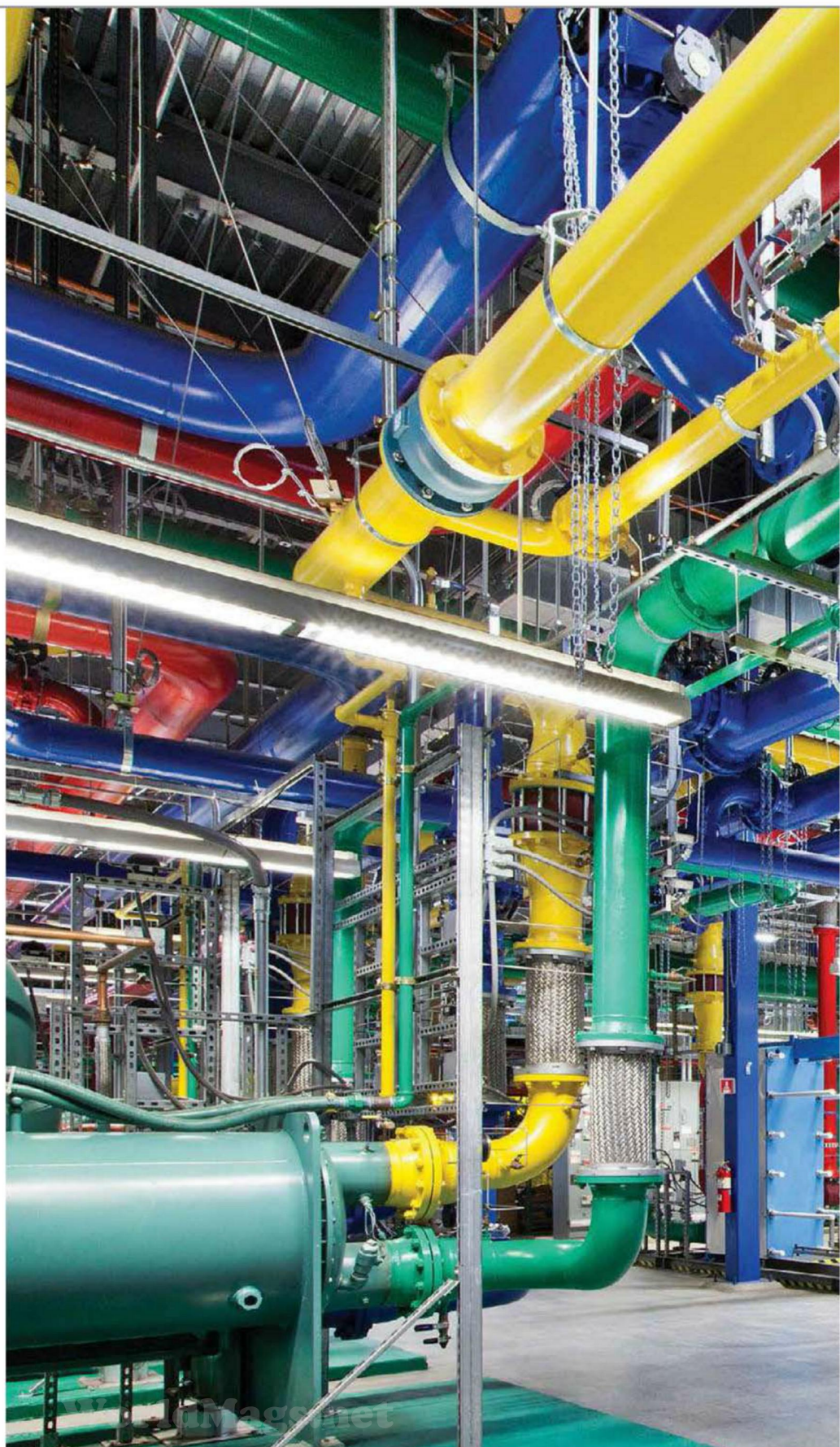
To keep its search engine (as well as many other products) running around the clock, Google maintains 13 large data centres across the globe. Data centres themselves, as facilities that house computer systems, have existed for decades. They're commonly used to back up data in large archives or – as is more common with the onset of cloud computing – access to IT resources. Data centres have grown in proportion with the expansion of the internet in the last 20 years. Today they can take up the same space as an industrial plant, require tight security (both physical and logical) and contain millions of pounds worth of computing equipment.

Currently, six of Google's data centres are located in the US, one in South America, three in Europe and three in Asia. They prioritise efficiency by focusing on cooling and the way power is distributed, with environmental impact in mind. The servers are a proprietary and patented modular format housed in their hundreds in individual shipping containers. But rather than using a huge, centralised uninterruptible power supply (UPS) for each facility, Google includes a battery on each server which is much more power efficient.

Data centres can run very hot if left unchecked – especially in summer. To combat this some are strategically located, like the Hamina facility in Finland, which uses the icy waters of the fjords to keep machinery cool.



© Google



THE STATS
GOOGLE IT

DATA CENTRES WORLDWIDE 13

FACILITY BUILD COST £400m

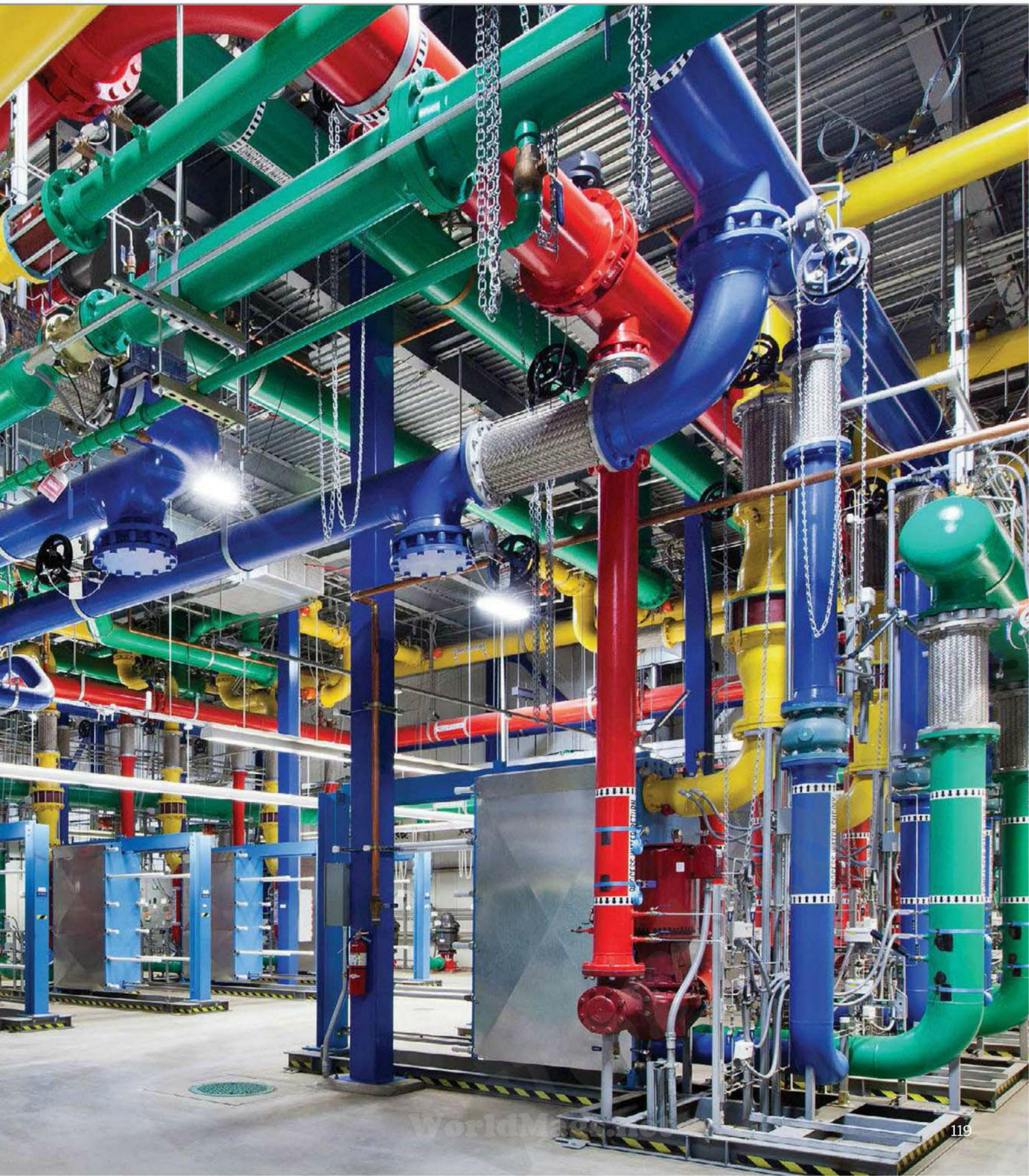
SERVERS PER CONTAINER 1,000+

CONTAINERS PER FACILITY 45+

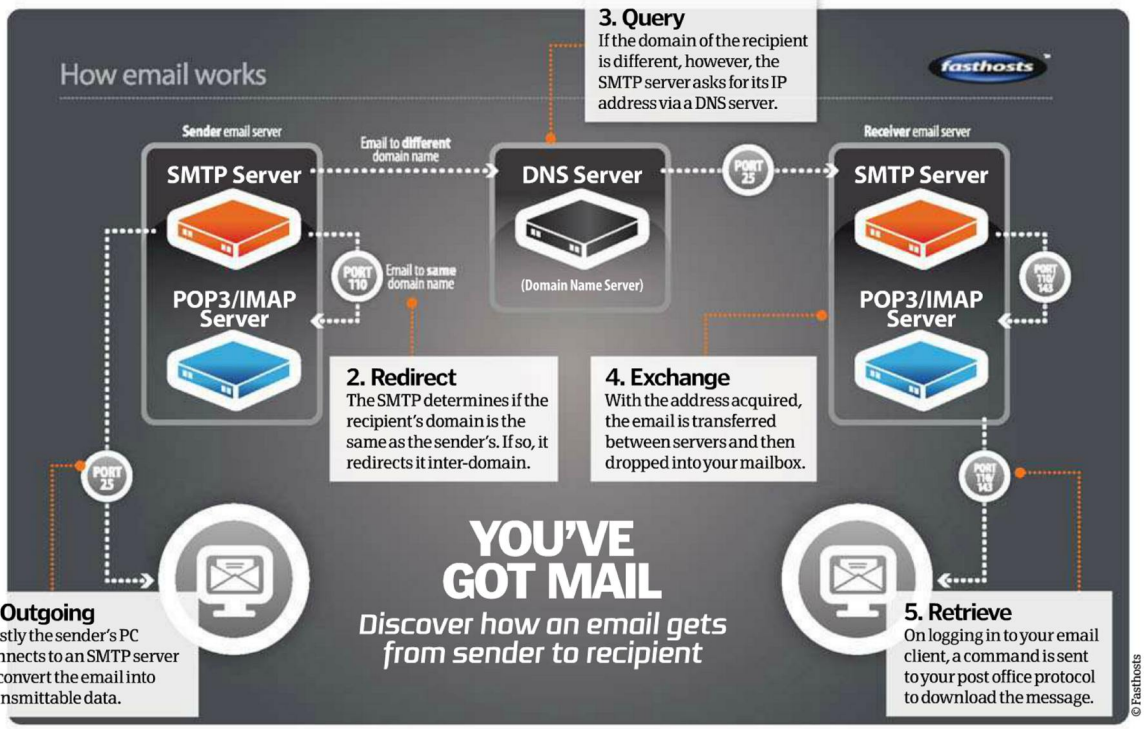
DATA CENTRE POWER USAGE 103MW

SERVER BATTERY EFFICIENCY 99.9%

DID YOU KNOW? *Google's entire server network in 1998 could be replicated thousands of times by a single container today*



"They can manipulate data on the flash drive, remotely deleting or disabling files at will"



© Fasthosts

How do you send and receive emails?

We explain how an email can cross multiple networks and entire continents in just a few seconds

An email is an electronic text message constructed and sent through an email client (such as Microsoft Outlook). Once written, the sending process begins, with the email client connecting to a simple mail transfer protocol (SMTP) server via the internet and through a DSL or line modem. The client then communicates with the SMTP part of your designated email server (for instance, GoogleMail) through a dedicated port.

During the transmission between your email client and server, your email client relays the header information of your email – in particular the recipient's address and the contents within the email body. At this point the SMTP converts the information to a TXT file to send across the web.

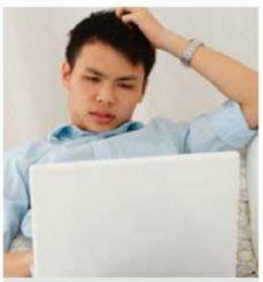
Based on the header information within your email, the SMTP server then contacts the recipient's correct email server. Using the '@' sign as a divider, the SMTP takes the second part of the address to determine the location of the recipient's server. If the domain name is the same as the sender's, the SMTP simply transfers the email information across. If the domain name is different, the SMTP contacts a DNS (domain name system) server and requests the exact IP address for the relating domain name's hosted email server, such as those provided by Fasthosts.

Once the IP address has been obtained, the sender's SMTP server sends out a signal message to the recipient's SMTP over the web and all its gateways informing them that they have received a message. From then, the two servers converse with each other and the email is transferred.

The TXT file converts back into its original form, dropping the message into the bottom of the addressee's mailbox. Finally, when the recipient logs in to their email client, it connects to the internet and commands the recipient's POP3/IMAP (post office protocol/internet message access protocol) server to download all pending messages for viewing on the local machine.


© Fasthosts

SMTP servers, like these at Fasthosts, are integral to the email-sending process, converting data and tracking down the recipient's address



JARGON BUSTER

Break through the complex lingo with our handy guide

Email client: An application used to view, compose and send emails. Examples include Microsoft Outlook, Microsoft Exchange or web-based ones such as www.mail.com.

Email server: A remote machine hosting your email, perhaps sourced from a freemail provider or a web-hosting company such as Fasthosts. The server is split into an SMTP server and a POP3/IMAP server.

Email address: Your unique online site for emailed material that uses a domain name, either individual to you or shared by a company/institution, etc.

DNS (domain name system): A remote server used to convert domain names to IP addresses (unique 32-bit numbers).

SMTP (simple mail transfer protocol): The part of the email server that starts the process for outgoing mail and receiving mail into the correct server.

POP3 (post office protocol)/IMAP (internet message access protocol): These parts of an email server store and download incoming mail for each user account.

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Self-destructing memory sticks

It sounds like a James Bond gadget but anyone can buy this high-security device

The convenience of the common memory stick is matched only by its liability – lose it, and there's nothing to stop anyone from accessing your files. To combat this, the data protection company ExactTrak has developed a memory stick called the Security Guardian, which houses a SIM card and battery, allowing the owner to track it via GPS and GSM. They can manipulate data on the flash drive, remotely deleting or disabling files at will and, because it has an independent, USB-rechargeable power supply, the Security Guardian needn't be plugged into a computer for the owner to do this. The real '007' feature has to be the kill signal: as a last resort, the owner can order the Security Guardian to self-destruct, sending a high-voltage charge from its power supply into the chip, destroying it and erasing all of the data on the drive in the process.



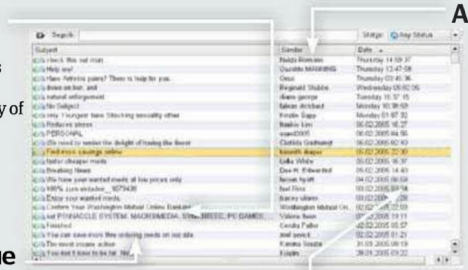
Spam attack!

Unsolicited emails explained

Spam consists of unsolicited messages sent via email, text or social networking sites. The messages, in general, are marketing tools used to advertise products. However, they are also used to spread malware and viruses.

Spammers harvest email addresses with spambots, software programs designed to scan the web for email addresses, and dump them in large databases ready for emailing. Automated software then sends batch emails out to thousands of addresses, one after the next.

Illegal
Illegal products are a mainstay of spam attacks.



Anonymous
While names appear in the 'Sender' column, they may not be genuine.

Frequency
Due to the minimal cost of sending spam, daily messages can be sent.

Vague
Vagueness of the header is an attempt to trick the recipient.

Wireless routers explained

What happens inside the magic boxes that get us online over thin air?

Wireless routers have revolutionised information access on the go. Yet there is nothing revolutionary about how they work. Internet data is essentially sent and received like over-the-air (OTA) television broadcasts, except in reverse. OTA signals are broadcast as radio waves and picked up by antennas attached to television sets. Each antenna converts the waves into electrical signals and sends them down wires to be turned into images by the television.

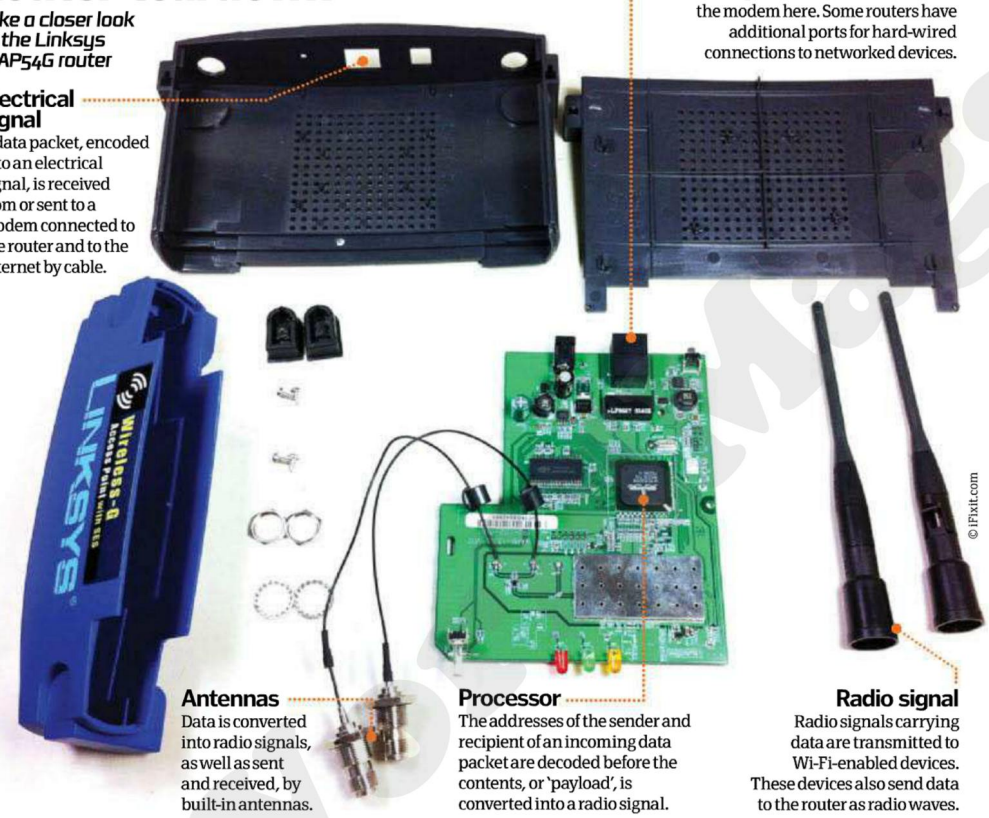
Wireless routers do things the other way around. They receive electrical signals from a modem connected to a cable on an internet service provider's network. These signals contain information in the form of data packets. A processor in the router decodes each packet's digital label or 'header'. This contains the unique numerical internet protocol (IP) addresses of the sender and intended recipient. A packet's payload of data (an email, for example) is then converted into a radio signal by the router and broadcast on the 2.4GHz or 5GHz frequencies via antennas. Wireless network adaptors in Wi-Fi-enabled devices intercept this transmission and convert it back into electrical signals.

Router teardown

Take a closer look at the Linksys WAP54G router

Electrical signal
A data packet, encoded into an electrical signal, is received from or sent to a modem connected to the router and to the internet by cable.

Ethernet port
The data packet enters the router from the modem here. Some routers have additional ports for hard-wired connections to networked devices.



Antennas
Data is converted into radio signals, as well as sent and received, by built-in antennas.

Processor
The addresses of the sender and recipient of an incoming data packet are decoded before the contents, or 'payload', is converted into a radio signal.

Radio signal
Radio signals carrying data are transmitted to Wi-Fi-enabled devices. These devices also send data to the router as radio waves.

© iFixit.com

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"Without a fast connection, cloud computing doesn't work"

CLOUD COMPUTING

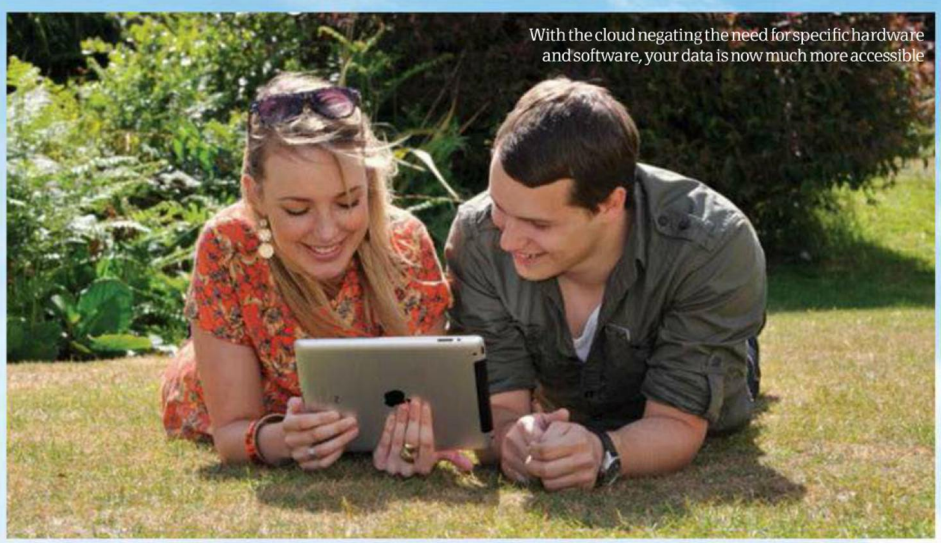
Now almost ubiquitous, cloud computing is changing every aspect of our digital lives

Over the last two years, cloud computing has rapidly developed into a technology that now touches anyone who uses the internet. In the past, you would install software on your computer, and locally store the data you created on your PC's hard drive. The cloud has been described as a paradigm shift away from desktop computing, with users moving to the 'webtop'.

The best way to explain how cloud computing works is to use a familiar example. Facebook now has over half a billion users. To open a profile, you don't have to buy any software to install. All you do is open Facebook in your favourite internet browser and sign up for a new account to start using the service. Every aspect of Facebook is hosted on remote server farms (or data centres, as they are also called), located all over the world.

The cloud works by making a secure connection between the device you are using to access the internet and the servers that hold the software you want to use. Any data you create – such as emails, spreadsheets or other documents – are also encrypted and securely stored online.

Any device can be used to connect to the cloud including smartphones, tablet computers, desktop and laptop PCs, netbooks and now the new range of notebook computers including the Chromebook, which are built specifically for using the cloud.



With the cloud negating the need for specific hardware and software, your data is now much more accessible

Why is cloud computing having such an impact on so many aspects of business and how people use their computers? The simple answer is, cost. With the cloud you needn't buy expensive software and update this regularly. You just buy the services you want, when you need them. And because the cloud is infinitely expandable, you never run out of processing power or storage space.

Using the cloud also allows you to use notebook computers, tablet PCs and smartphones that don't need masses of computing power or capacity. All your device needs to do is connect to the cloud and efficiently run your web browser. All the processing is done on the servers that the cloud is using.

In the past, if you connected your computer to a server to buy something, the online retailer had to

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5 TOP FACTS CLOUD

Office 365
1 With the launch of Microsoft's Office 365 you can use familiar Office applications online, and gain all the benefits that the cloud has to offer.

Facebook goes mobile
2 Social networks continue to expand and take advantage of the cloud. Around 200 million users of Facebook now access their profiles on mobile devices.

Cloud expansion
3 According to the latest research from IDC, the amount of stored data in the digital universe is now 1.2 million petabytes, with 15% of this stored in the cloud by 2020.

The perpetual beta
4 The cloud offers what Tim O'Reilly called a 'perpetual beta'. When a new feature is developed, it's switched on. There's no need for downloads or installations.

Data centres
5 Google is reported to have about 1 million servers, which represents around two per cent of the server population in the world supporting its cloud-based services.

DID YOU KNOW? *NetCentric tried to trademark the term 'cloud computing' in 1997, but gave up two years later*

NG

spend a great deal of time and money setting up their servers before they could open their store. This usually meant choosing a server operating system such as Apache, Windows Server or Linux. The cloud sweeps these constraints away, as servers used in the cloud are virtual in that they are not reliant on any specific operating system or hardware platform.

The best way to think of the cloud is like a layer cake. If you use Twitter, when you send a tweet you are connecting with the first layer of the server cake. You see this layer in the internet browser you are using. When you press 'send' to post your tweet, you then interact with the next layer of the cake. This is called 'middleware', and connects the layer you see in your browser window with the hardware that actually supports the cloud. The last layer is the physical server that is located in massive air-conditioned monolithic buildings dotted all over the world. Apple recently opened a new data centre to support its iCloud service.

The idea of cloud-based applications and data storage may not be a new one, but only recently have we enjoyed broadband connections to the internet. Without a fast connection, cloud computing doesn't work. Imagine if you were using Google Docs to write a letter and had to wait for each word to upload and appear on your screen because of a slow connection. Broadband provides you with the speed to make using email, word processors, etc, efficient.

One of the main concerns with using cloud-based applications is security. The April 2011 breakdown of

THE COMPUTING STACK

Cloud computing uses the concept of the 'stack' that includes layers that enable users to access online services such as Google Docs with any device that can connect to the internet. Stacks and layers have been common in corporate data management for decades, but now, thanks to the cloud, we're all experiencing how these hardware and software components work together.

SERVER

The foundation of the cloud
No matter how you approach the cloud, the server is always at the heart of every type of cloud-based service. Servers can be physical racks of hardware, or virtual servers (software that acts like a server) used to offer cloud-based services.

Outsource your IT
Infrastructure as a Service (IaaS) enables a business to move its hardware and software requirements to a third party, who leases these back to the business as a cloud-based service. Businesses are attracted to IaaS as the cloud service provider handles the maintenance costs and all software updates. Data storage is a classic use of IaaS, as the cloud can offer infinite storage that can expand and contract as needed.

INFRASTRUCTURE AS A SERVICE

[Examples]
Amazon EC2/GoGrid (www.gogrid.com)
Iomart Hosting (www.iomarthosting.com)
Rackspace Cloud (www.rackspace.com/cloud)

PLATFORM AS A SERVICE

[Examples]
Windows Azure/Google App Engine/Force.com (Salesforce.com)
Long Jump (http://longjump.com)
WaveMaker (www.wavemaker.com

Build applications without the cost
Platform as a Service (PaaS) cloud applications allow you to rent the hardware (servers), operating system and ancillary software you need, all delivered via the cloud. As the development environment is in the cloud, it can be updated without the cost of new hardware or software being purchased.

SOFTWARE AS A SERVICE

[Examples]
Google Docs/Salesforce.com
DropBox/Spotify/Gmail

Software services on demand
Many cloud services are grouped under the heading Software as a Service (SaaS), where the application and data are all produced and stored online. A software application is delivered online and the cloud is used as your virtual computer, running the application via your client device.

CLIENT

[Examples]
Tablet computers including the iPad/Samsung Galaxy/HP TouchPad.
Desktop PCs running any operating system/ smartphones from Apple and HTC
Netbooks from Asus, Samsung, Toshiba and Acer

Cloud connection
The client is the first piece of the jigsaw. The digital device you use to access the web is your client. Add to this your favourite web browser and your client is ready to use the cloud. What's new about today's cloud computing clients is that they can be designed for cloud, such as the Chromebook and Kogan Agora.



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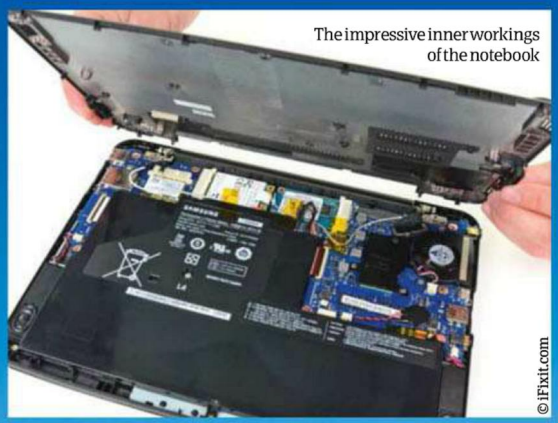
"Storing digital info in the cloud must be approached carefully"

security on Sony's PlayStation online gaming services is only one of a long line of cyberattacks on web-based services. Businesses in particular are still concerned that moving sensitive customer information from their own secure servers into the cloud could compromise the security of this data. Even for individuals, security is still an issue. Storing documents, emails and any other digital information in the cloud must be approached carefully.

Your connection with the cloud is done over a secure network, and the data stored on the servers is also encrypted and backed up, but we still periodically see news headlines that hackers have yet again circumvented what was thought to be robust security in the cloud. The advice is to keep a backup of your data offline, and use reputable cloud service providers such as Google or Amazon. Always have your firewall active and your anti-virus software up to date. If you're connecting over a wireless connection, make sure this is secured with WPA (Wi-Fi Protected Access), which is now the industry standard.

For businesses, cloud-based costs will be linked to the services they've bought. A good example is Salesforce.com, a market leader in the sales management market. Users purchase varying levels of service depending on the sophistication of the features. Many of the online cloud-based services use this method of leasing users just the features they need. Microsoft Office 365 costs £4 a month to access all the applications available.

The cloud offers anyone the opportunity to use the latest applications, for low or zero cost once you've paid for your connection. As the applications and other services available in the cloud mature, the shift away from clunky desktops and costly software and hardware upgrades will be complete.



The impressive inner workings of the notebook

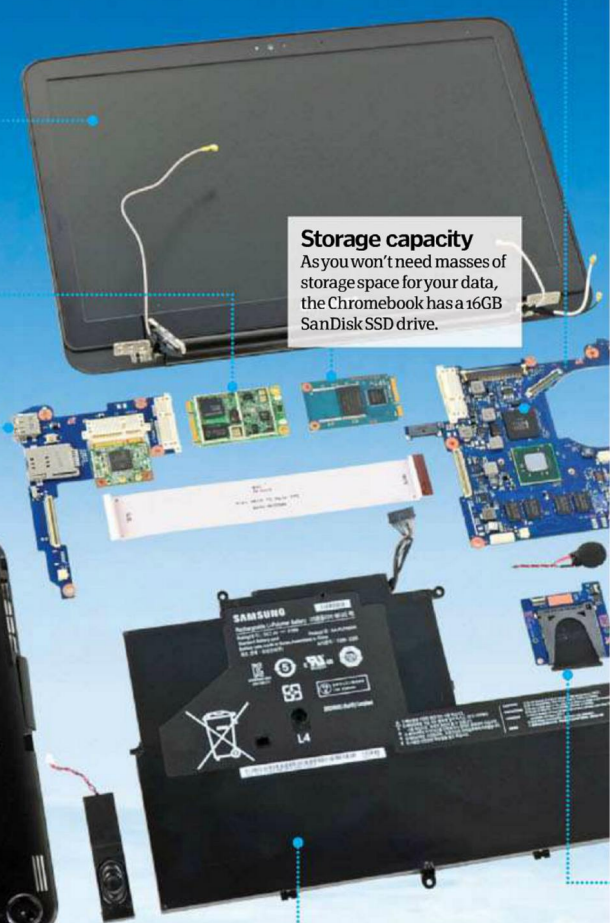


On-board memory
As you will only need to run your favourite internet browser to access the cloud, the Chromebook has just 2GB of RAM.

Internet connectivity
The Chomebook gives you Wi-Fi and 3G wireless connections, to ensure you can always stay connected.

Screen real estate
The larger 12.1-inch screen makes this computer more of a notebook PC than a netbook.

Processing power
Using the cloud doesn't require massive amounts of computing power. The Intel Atom dual-core N570 processor is clocked at 1.66 GHz.



Storage capacity
As you won't need masses of storage space for your data, the Chromebook has a 16GB SanDisk SSD drive.



Built to last
The designers of the Chromebook understand you'll be using your machine in all environments, which is why the case is made from rubberised plastic.

All-day working
Because of the low-powered processor in use battery life is excellent, giving you up to 8.5 hours of cloud-based working.

Safe as houses?

You can take several practical steps to ensure that your use of the cloud is as secure as possible. If you're using a desktop computer, make sure you have a firewall enabled, anti-virus software installed and you use strong passwords to access the cloud services you use.

When you make a connection to the cloud, the data you send should be encrypted. However, don't be complacent as it could still be intercepted. Any stored data you have in the cloud is usually encrypted and backed up, but always try and keep an offline copy of any essential data. With wireless internet connections, this risk is even greater. But the good news is that security systems such as WPA offer good levels of security. And if you are in business, set up a VPN (virtual private network) that ensures a secure link between your client computers and the cloud servers you're using.

The cloud by its open nature can't be completely secure at all times. However, you are not powerless and at the mercy of hackers. If you're sensible about the security you have control over – strong passwords, up-to-date virus definitions and a good firewall – you can minimise your risks.



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DID YOU KNOW?



What is cloud computing?

If you use Facebook, communicate with Gmail, upload photos to Flickr, move data using DropBox or have just signed up to use Office 365, you're already using cloud computing. The cloud is a host for apps you would normally install and data that you store on your PC's hard drive. It's a server that you can access with any device that has a broadband connection.

DID YOU KNOW? *To ensure the hardware platform that the cloud runs on is secure, servers are housed in disused nuclear bunkers*

Inside the... Samsung Chromebook series 5

Access the cloud with a specialised notebook

Because the cloud stores your applications and their associated data online, the notebook PC you use to connect with the cloud doesn't have to be as powerful. The Chromebook is one of the first notebook PCs to be built specifically for cloud. The compact notebook PC sports an Intel Atom N570 processor, 2GB of memory and just 16GB of SSD (solid-state drive) storage, as you don't need gigabytes of hard drive space or processing power when using the cloud.

The Chromebook also has Wi-Fi and 3G connectivity built in, meaning you can connect with the cloud no matter where you are. As the first notebook of its kind, the Chromebook could be the template for all future cloud-enabled notebook computers.

Keeping cool
The tiny heat sink that cools the atom processor ensures that your Chromebook stays cool, even during mammoth cloud-computing sessions.

Typing and scrolling
The keyboard and trackpad on the Chromebook are well designed and will take even the heaviest of pounding.



Chromebook and cloud are a heavenly match

Memory card reader
To get your photo into the cloud, a handy SD memory reader has been included on the left-hand side of the Chromebook for easy access.

© Samsung

PROS & CONS



- ✔ No software to install or upgrade
- ✔ Access applications and your files from any internet-connected device
- ✔ Use lower-powered – and less expensive – computers to access the cloud
- ✔ Instantly share documents and other data with anyone online
- ✔ Infinite storage capacity in the cloud
- ✘ Potential security threats to your data
- ✘ Requires constant internet connection
- ✘ Application features can be limited when compared to installed software
- ✘ Performance of your applications is directly linked to the speed of your internet connection
- ✘ Your cloud host could go out of business

STATS TO BLOW YOUR MIND...

$100 BILLION

The amount that could be spent by SMEs (small to medium-sized enterprises) on cloud services by 2014, according to research by AMI Partners.

5 BILLION

The staggering number of photos uploaded to Flickr, as of September 2010. Over a third of web users store photos online.

2014

IDC predicts that by 2014, over a third of all software will be delivered as cloud-based services.

50 MILLION

The estimated number of physical servers in the world, with over 5 million new servers installed each year.

359 MEGATONS

By 2020, powering the cloud will produce 359 megatons of CO_2.

The number of users Facebook has surpassed is...

750 MILLION

"Siri uses probability and mathematical algorithms to analyse the smallest units of spoken sound"

Apple's voice-recognition tech



How Siri works

Apple's new personal assistant isn't magic but the culmination of 60 years' development into natural language processing

Pivotal to Siri's operation is natural language processing, a field of computer science and linguistics that has slowly advanced over the past 60 years. Natural language processing, which itself contains myriad sub-processes such as speech segmentation, is the overarching system that allows Siri to accurately – in most cases – respond to your commands. Key to the whole function, however, are statistical models.

Statistical natural language processing, as used by Siri, employs chance and probability to resolve the required range of sub-processes. These processes often use corpora (a large volume of known, real-world data) to derive a set of abstract rules from which to interpret received data (ie your voice command), in addition to a statistical model, such as the 'hidden Markov model' (HMM).

The HMM is a statistical system that, through probability and mathematical algorithms, analyses a spoken command's sequence of phonemes (the smallest unit of spoken sound) to generate a chain – the completed chain forming a single word. It does this by assigning a probability score to each phoneme, before determining which word the individual phonemes amount to.

The statistical models, however, rely on the system's training data – eg the corpora – referencing acoustic models, word lists and probability networks at multiple points. This is because while the system is finely tuned to deliver completed chains, the chain and the chain's context – be that meaning or position within an extended command – varies depending on non-statistical variables.

Due to the vast complexity and processing power necessary to analyse any spoken command, the majority of Siri's natural language processing is handled in the cloud, with a handset consulting remote servers to quickly supply a response. This process is explored in detail in the 'Speech to text step-by-step' diagram above.

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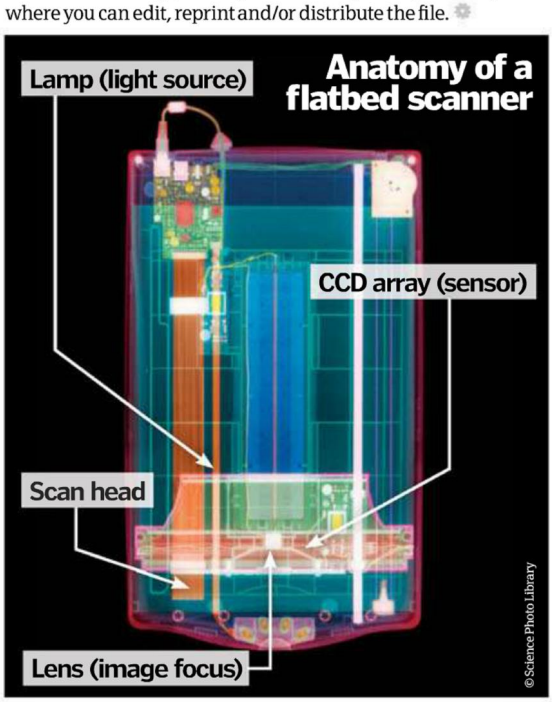
Scanners explained

How do these desktop devices turn printed media into digital files?

Flatbed scanners use a beam of light, mirrors, a focusing lens, filters and a sensor called a charge-coupled device (CCD) array to capture the image of a physical photo or other paper document and convert it into a digital file for use on your computer.

The lamp and mirrors are part of the scan head, which is a sliding mechanism that slowly passes beneath the document to be digitised. Once you have placed the paper face down on the flat glass bed, closed the lid and pressed 'scan', the scan head will begin to pass underneath the page. As it does so, the lamp casts a bright beam of light onto the document above to illuminate it. The first mirror on the scan head – positioned just behind the lamp as it passes by the document – is angled so that it reflects the now-illuminated part of the page onto a second mirror. The second mirror then reflects the image onto a third. Each mirror is slightly concave which means that the image becomes progressively smaller as it is reflected from one mirror to the next in the chain.

At this point the significantly scaled-down picture is reflected from the last mirror through a lens to focus the light through colour filters (usually red, green and blue) and onto the sensor. This sensor (the CCD array) consists of numerous light-sensitive diodes, which convert light energy (photons) into electrical energy (electrons). This produces an electronic, or digital, version of the image, which you can then port to your computer where you can edit, reprint and/or distribute the file.



Music-recognition software

For those moments when you just have to know what that song is, music-identification software like Shazam can come to your aid

Shazam, the first music-identification app, helps you find songs by doing exactly what you would normally do – research – only much faster. When you open the app and hold it up to hear the music, it renders what it's hearing down into a numerical code or signature using a specific algorithm. This signature is also used by the library of millions of songs that Shazam's central database houses. The app communicates with this database and simply compares 'fingerprints', matching the song you've recorded to the song in the system by comparing these numerical signatures.

While matching every element of every song would be an immense task, Shazam breaks this down into something much simpler, creating a graph that plots out three 'dimensions' of the music: frequency vs amplitude vs time. Most of the graph will be relatively uniform, but 'peaks' in each of these dimensions will be unique to the song. It's these peaks the service focuses on, allowing identification of each song.

The process isn't perfect and, in its early days, live performances caused problems due to the variations in the music. However, with the Shazam algorithm being refined all the time, and services like Midomi being able to identify a song simply by you humming it, it's clear that there's never been a better time to look for new music, or a more powerful set of tools to help you be able to find it.

Naming that tune step-by-step

STEP 1



Initial scan
Once activated, the music-identification app boots up and 'listens' to the song to get a sample it can use. Shazam requires five seconds of music to do this.

STEP 2



Identifying peaks
Once the music sample is acquired, the recognition software identifies the song's 'peaks' in a spectrogram (visual representation of the sound).

STEP 3



Comparing
The app then communicates – via Wi-Fi or 3G – with its central database and checks its information against the songs contained there.

STEP 4



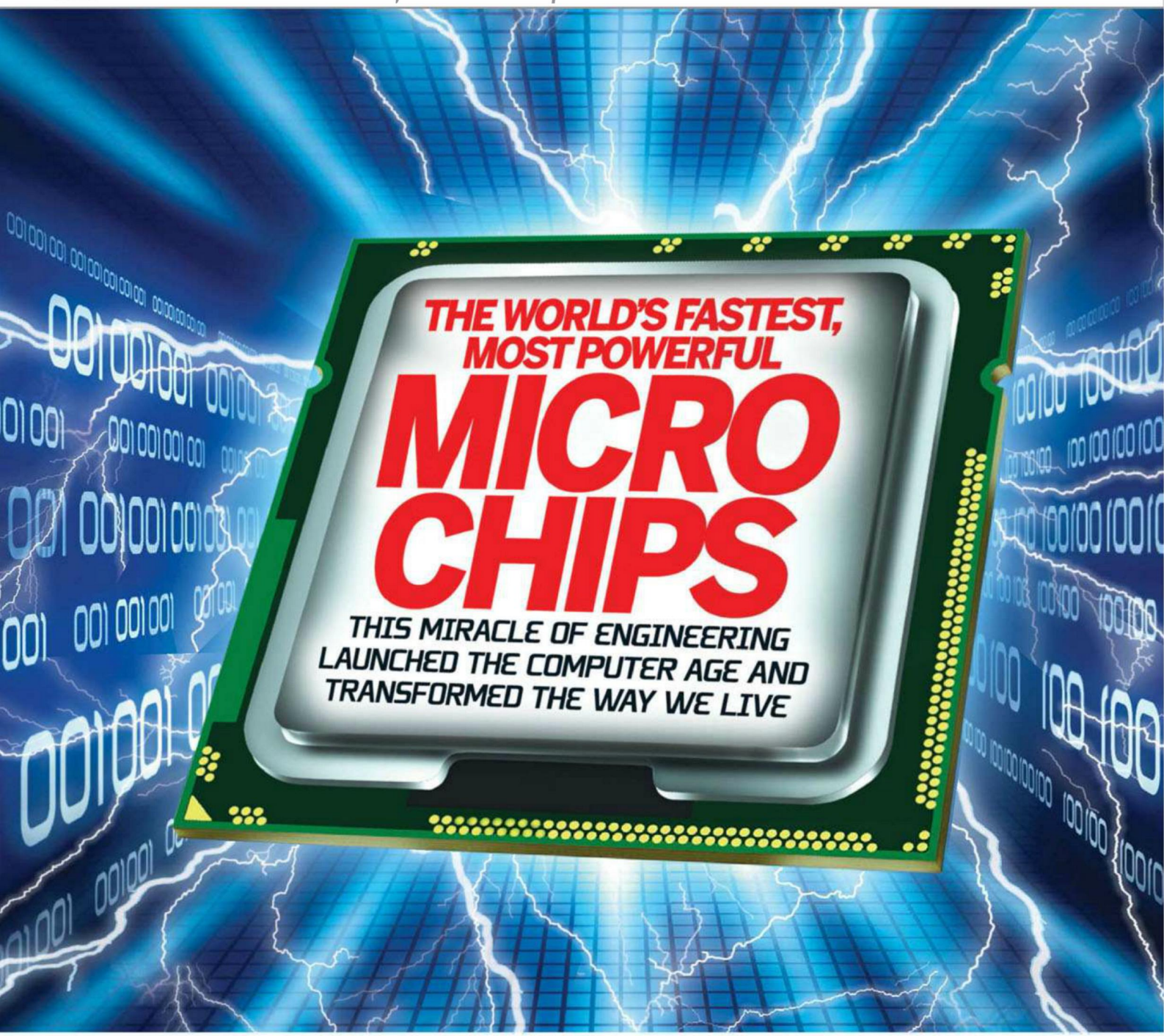
Identification
If the app finds a match, it will tell you. If not, it will ask for more information or say there is no match. This can take as few as four seconds.

STEP 5

Purchasing the song
Several apps give you the option of purchasing the song, linking you to iTunes to buy it directly, as well as letting you watch the video or read the lyrics.



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In 1949 it was boldly predicted that 'Computers in the future may weigh no more than 1.5 tons.' To the author, such a 'lightweight' machine would be almost inconceivable. The only computer around at that time was the ENIAC, a Goliath calculating machine that weighed a colossal 27 tonnes (30 tons) and measured 30 metres (98 feet) in length. The brains of the machine consisted of 17,468 vacuum tubes, lightbulb-like plugs that act as transistors, switching the electrical current on and off to correspond with the 1s and 0s of the binary code being used.

Imagine if you could travel back in time and present the author of that article with an iPhone. Inside the iPhone is a circuit board mounted with over a dozen microprocessors, each tens of thousands of times more powerful than the 27-tonne ENIAC, and each no larger than a fingernail. The iPhone sill relies on transistors to switch between 1s and 0s, but instead of using 17,468 hot and power hungry vacuum tubes, the iPhone harnesses the collective computing power of hundreds of millions, even billions of infinitesimally small transistors mounted on a miracle we call the microchip. One and a half tons? Try 137 grams (4.8 ounces).

The microchip is nothing short of an engineering marvel. Since the first silicon-based transistors began to replace vacuum tubes in the early Fifties, electrical engineers have dreamed up ingenious new ways to shrink the components of an electrical circuit (transistors, capacitors, resistors, diodes, etc) into a wafer-thin package. The game-changing

5 TOP FACTS MICROCHIPS

Lightning switches
1 The nanoscale transistors found on modern microchips can be turned on and off at an unthinkable rate of over 100 billion times a second.

Too many zeros
2 With hundreds of millions of transistors on each chip, Intel estimates that it ships 10,000,000,000,000,000,000 (that's 10 quintillion) transistors every year.

Moore's challenge
3 Moore's Law isn't a 'fact' like Newton's Laws of Motion. It's merely a prediction that transistor capacity will double roughly every two years; one that has held true for 46 years.

Nano transistors
4 The latest chip-making technology from Intel produces transistors that are so small that an amazing 30 million of them could fit on the head of a pin.

Endless supply
5 The versatile material upon which the microchip is constructed, silicon is the second-most abundant element in the Earth's crust. It is beaten only by oxygen.

DID YOU KNOW? *Early computers ran on vacuum tubes. ENIAC, the first digital computer, required nearly 18,000 of these tubes*



The A5 microprocessor is installed in every iPhone 4S


A modern, flexible electronic circuit above a traditional wiring loom

© Science Photo Library

"Inside the iPhone is a circuit board mounted with over a dozen microprocessors, each tens of thousands of times more powerful than the 27-tonne ENIAC"

breakthrough was the 1958 invention of the integrated circuit, the mother of all modern microchips. Prior to 1958, electronics manufacturers had to hand-solder and wire every component on their increasingly small circuit boards. With the integrated circuit, every component of the circuit is cut from the same silicon.

But even the breakthrough of the all-in-one circuit doesn't explain how modern chipmakers can mass-produce minuscule squares holding hundreds of millions of transistors. To do that, we must enter the 'fab'. Fabs are the multi-billion-dollar facilities that house the clean rooms in which microchips are born. Clean rooms are the most tightly controlled environments in the world. When you are fabricating materials that are 45 billionths of a metre wide, the slightest surge of static electricity or microscopic dust speck could ruin everything. Fab technicians dress in head-to-toe 'bunny suits' to lower the risk of contamination.

To understand how microchips are made, it is useful to think of building a house with a child's Lego set. But instead of building each wall one at a time, do it layer by layer. Start with a flat square of Lego pieces that traces the outline of the four walls. Now add the next layer of Lego bricks building upward until you have four full walls.

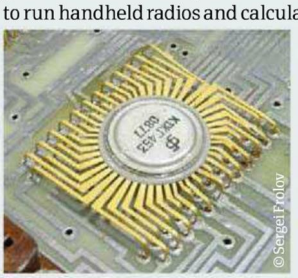
Microchips are fabricated using the same layering technique – up to 40 layers for the most complex chips. The first layer is a thick (1mm/0.04in) base of ultra-pure, polished silicon. Silicon is the material of choice because of its semiconducting properties, which means it can act as a conductor or insulator of electricity depending on the job it needs to do. Engineers can change the conductive property of silicon by 'doping' it with different chemical impurities. Other layers are silicon oxide insulators, photoresistant coatings and metal (copper and tungsten) for the wire connections.

Using a process called photolithography, chipmakers can imprint precise blueprints onto each layer and etch away the unnecessary sections with chemical solvents. Intensely focused lasers enable chipmakers to trace lines to an accuracy of 5nm. Each chip is subjected to multiple rounds of testing before it is installed in your mobile, digital camera, car, toothbrush or anything else you can think of. Indeed, there is no corner of modern life that has not been fundamentally changed by the invention of the microchip. And with news of molecular transistors and quantum-scale circuits, the future is looking set to surpass even our wildest predictions.

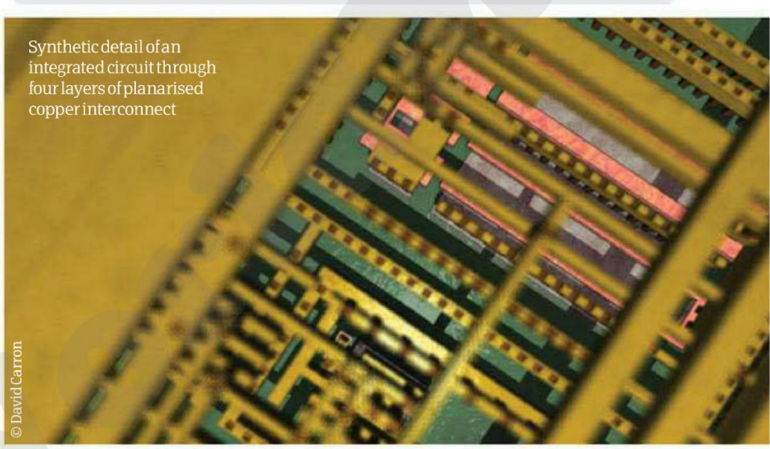
History of the microchip

The history of the microchip starts with the transistor in the mid-20th century. A transistor is a device that amplifies a signal or powers a switch with nothing more than a jolt of electrical current. The first transistors were made from vacuum tubes and looked like small lightbulbs. Early computer pioneers discovered that transistors could be used as switches to run simple logic programs. As computer programs became more and more complicated, engineers required more transistors.

But vacuum tubes failed often, produced too much heat and required lots of energy to run. In 1947, three researchers at Bell Labs in the USA proved that a transistor could be built from the semiconducting element germanium. These tiny transistors could be soldered onto circuit boards to run handheld radios and calculators. But to build even smaller, more powerful devices, engineers needed to pack more transistors into a smaller area. In 1958, Robert Noyce at Fairchild Semiconductor and Jack Kilby at Texas Instruments independently discovered that an entire circuit board could be stamped from thin layers of silicon, a cousin of germanium. Every generation of microchip packs more and more transistors per square centimetre. Dual-core Intel processors include over a billion transistors.


© Sergei Frolov

An early USSR-made integrated circuit


Synthetic detail of an integrated circuit through four layers of planarised copper interconnect

© David Carron

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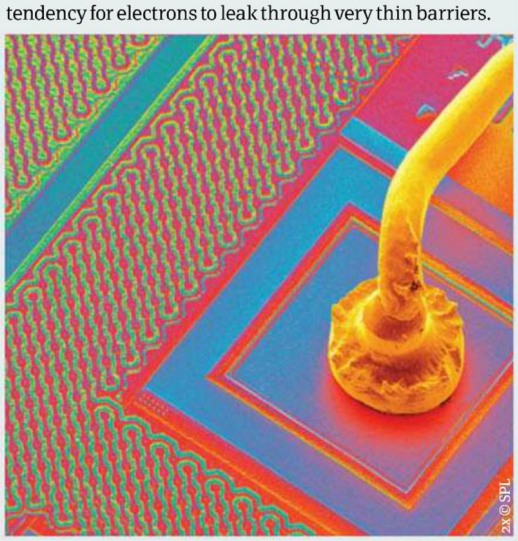
"Microchips start as highly polished silicon discs, laser-sliced to 1mm (0.04 inches) thick"


An ant holding a microchip in its mandibles

From micro to nano

When Intel released its first microprocessor in 1971, it held 2,300 transistors, a mindblowing quantity for a chip the size of a fingernail. Six years earlier, Gordon Moore, one of the founders of Intel, published a paper in which he predicted that the number of transistors incorporated into a chip would double every 18 to 24 months. Moore's Law, as it's now known, has remained true for over 40 years, challenging generations of engineers to build impossibly small, incredibly powerful microchips.

Intel's latest chipsets hold hundreds of millions of transistors. To cram so many transistors into such a small space, engineers must work at the nanoscale (billionth of a metre). A human hair is 100,000nm in diameter, while the smallest transistors in production boast widths of only 22nm! The manufacture of nanoscale components relies on breakthroughs in photolithography, the use of ultraviolet light rays to etch super-precise patterns onto photoresistant film. As chip components approach the atomic scale, however, the rules of physics change. To extend Moore's Law, engineers will need to develop new materials and designs that resist quantum tunnelling, the tendency for electrons to leak through very thin barriers.


2x © SPL

A coloured SEM photo of one of an integrated circuit's micro-wires


Microchips are manufactured in high-tech clean rooms, or 'fabs', to keep contamination to an absolute minimum

© NASA

Microchip fabrication

Microchips start as highly polished silicon discs, laser-sliced to one millimetre (0.04 inches) thick. The nanoscale components of the chip (transistors, resistors, capacitors, etc) are then built upwards layer by layer. Modern chips have as many as 40 layers. The design for each layer is produced as a mask through which ultraviolet laser light is shone. The pattern is imprinted on a layer of photoresistant material. The pattern is then etched away by chemicals, leaving an intricate design in the silicon layer below. The exposed silicon is then treated with doping agents that give the material its desired electrical properties. Layer upon layer of silicon, insulators and photoresist are added until all of the components are constructed. Then, using the same photolithography technique, layers of metal are cut to leave a pattern of copper wires connecting each tiny component of the integrated circuit.

Anatomy of a 50nm transistor

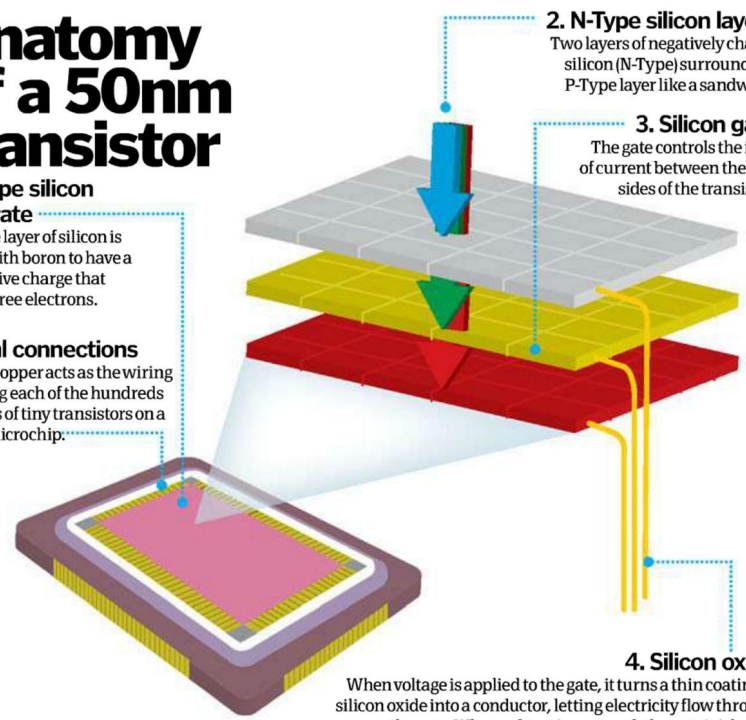
1. P-Type silicon substrate
The base layer of silicon is doped with boron to have a net positive charge that attracts free electrons.

2. N-Type silicon layers
Two layers of negatively charge silicon (N-Type) surround the P-Type layer like a sandwich.

3. Silicon gate
The gate controls the flow of current between the two sides of the transistor.

4. Silicon oxide
When voltage is applied to the gate, it turns a thin coating of silicon oxide into a conductor, letting electricity flow through the gate. When voltage is removed, the gate is 'closed'.

5. Metal connections
A layer of copper acts as the wiring connecting each of the hundreds of millions of tiny transistors on a modern microchip.




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HEAD 2 HEAD MICROCHIP MILESTONES


© Juril

1. THE FIRST

Integrated circuit

In 1958, Jack Kilby dreamed up the idea of constructing all of a circuit's components out of germanium. He won a Nobel Prize in 2000.


© Rimb

2. GAME-CHANGER

Intel Core 2 Duo

Intel started selling limited dual-processor chips in 2002, but it was the Core 2 Duo, in 2006, that really revolutionised the industry.



3. THE FUTURE

Molecular transistors

Researchers have turned a single molecule of benzene into a functioning transistor, opening the door for a great leap in computing power.

DID YOU KNOW? *Compared to its first microchip released in 1971, Intel's latest chips run 4,000 times faster*

MICROCHIPS AND YOU

Take a look at just a few of the everyday objects that depend upon microchips

Coffee maker

The microchip inside the Tassimo single-serving coffee maker makes it a 'smart' appliance. The chip reads the barcode on each single-serving disc and calculates the precise amount of water and brewing time to make the perfect cup of coffee, tea or hot chocolate.


© Thu45

Digital camera



© Roberts



© Nebrot

Prism
A trichoic prism splits incoming light into different wavelengths.

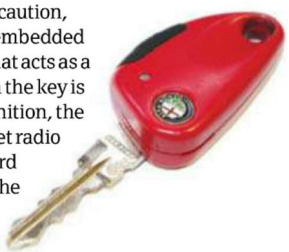
Mixed signals
The signal levels from each of the millions of pixels is reassembled as an image.

Red, green, blue
A 3CCD digital camera has three photo sensors, one for each primary colour.

Pixel power
Each pixel on all three photo sensors uses transistors to convert light into electrical impulses.

Car keys

As an anti-theft precaution, many car keys are embedded with a microchip that acts as a transponder. When the key is inserted into the ignition, the chip sends a discreet radio signal to a dashboard receiver that gives the green light for the engine to start.



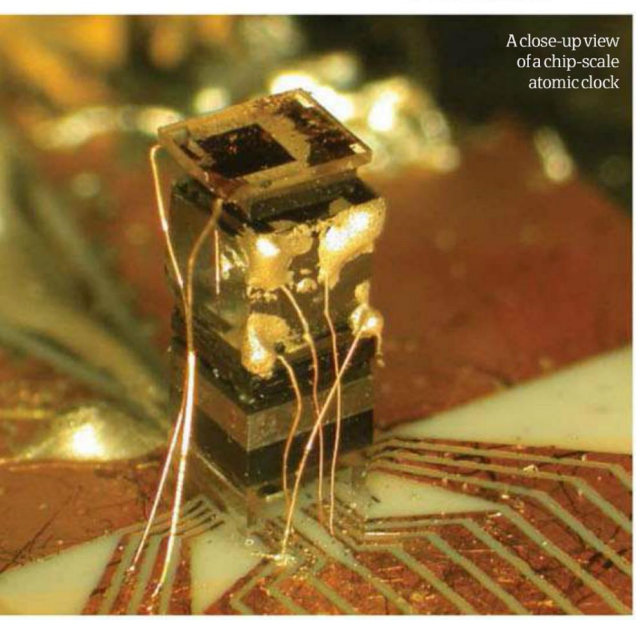
Clock radio

The transistor radio was the first commercial product in the world that ran by microchip. The millions of transistors on the chip in your clock radio amplify the incoming signal so we can hear the music.

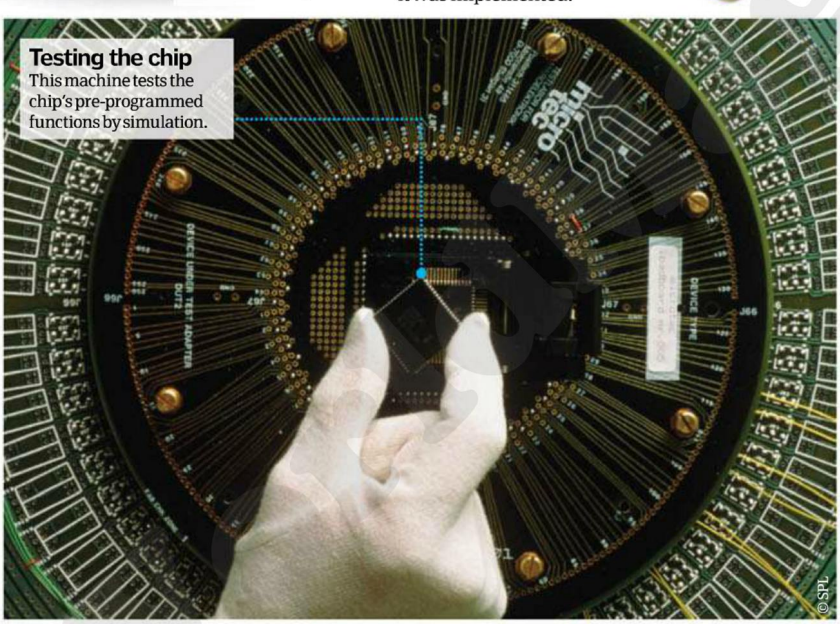
Credit card

The US is following the lead of European banks and ditching the magnetic strip for an embedded smart chip. The chip holds all account information and can only be accessed with the correct four-digit PIN. Credit card fraud in France is down 80 per cent since it was implemented.





A close-up view of a chip-scale atomic clock



Testing the chip
This machine tests the chip's pre-programmed functions by simulation.

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"The drum is first given a uniform static charge and then a laser beam flashes across the surface"

Inside laser printers

How is it possible to print text and pictures using a beam of light?

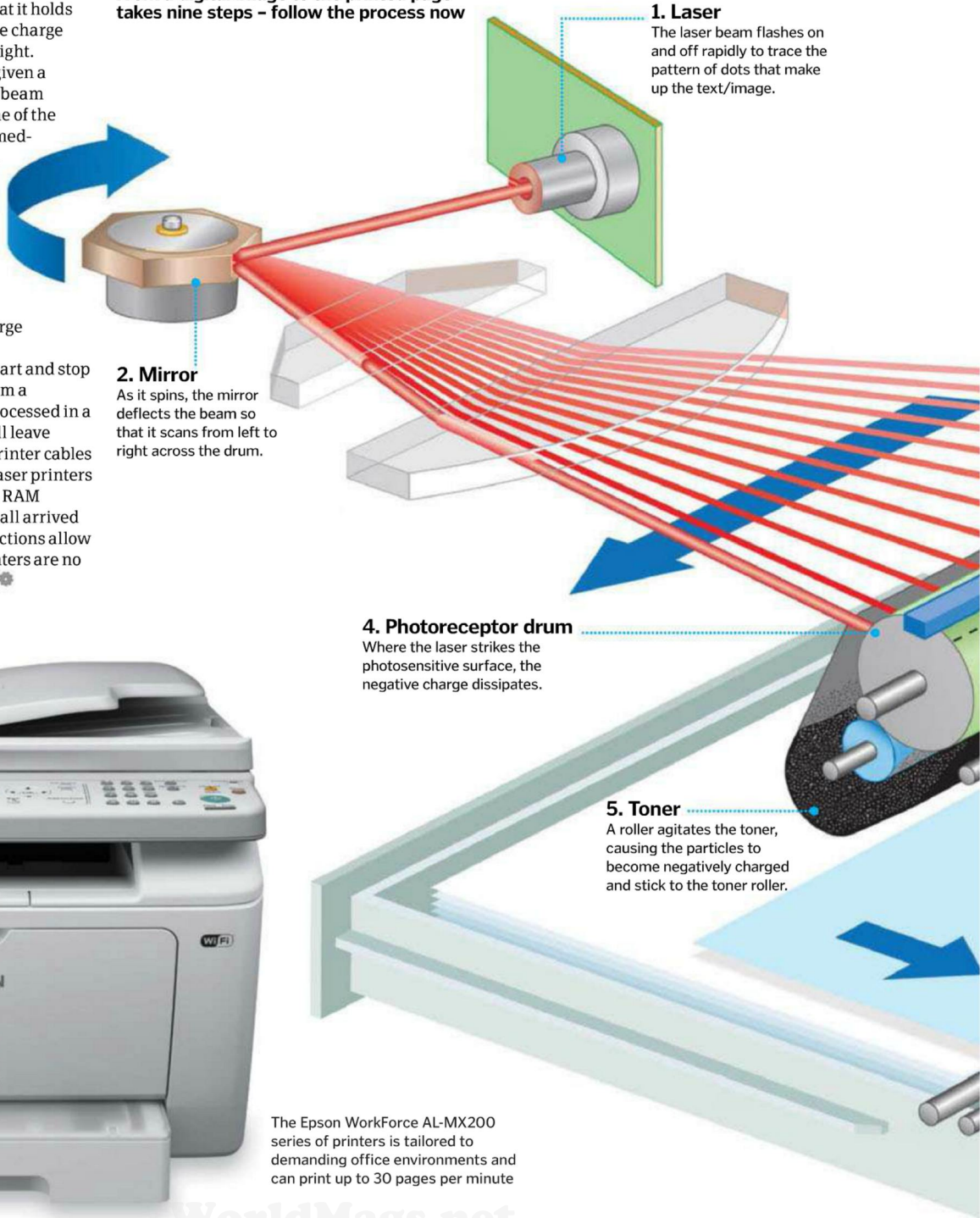
At the heart of every laser printer is a drum coated with an organic photoconductor (OPC). This substance has the unusual property that it holds an electrical charge in the dark, but the charge will dissipate if the OPC is exposed to light.

To print an image, the drum is first given a uniform static charge and then a laser beam flashes across the surface, erasing some of the charged areas, like drawing on a steamed-up window with your finger. If you roll this drum through a trough of specially charged pigment particles – called toner – they will stick to the uncharged sections of the drum and be repelled from the rest. You can then roll this onto a sheet of paper to transfer the image. To stop the toner falling off the paper as soon as the charge fades, it must be melted into place.

Unlike an inkjet printer, you can't start and stop the printer drum as it receives data from a computer. The entire page has to be processed in a continuous operation, otherwise it will leave smudges or lines on the paper. Early printer cables couldn't transfer data fast enough so laser printers had to use large amounts of expensive RAM memory to buffer the page until it had all arrived from the PC. Nowadays fast USB connections allow direct printing, and desktop laser printers are no more costly than their inkjet cousins.

Painting with light

From a digital image to the printed page takes nine steps – follow the process now





The Epson WorkForce AL-MX200 series of printers is tailored to demanding office environments and can print up to 30 pages per minute

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KEY DATES
LASER PRINTING

1938 Chester Carlson develops a way of copying a printed page using electrically charged dry toner.

1960 The only company interested in Carlson's invention is the Haloid Photographic Company, which later becomes Xerox.

1969 Gary Starkweather (right), a researcher at Xerox, modifies the photocopier principle to allow it to print.



1984 The HP LaserJet is the first desktop laser printer. It weighs in at over 32 kilograms (70 pounds).

2010 Restrictions are placed on toner cartridges on US flights after laser printers filled with explosives are discovered.

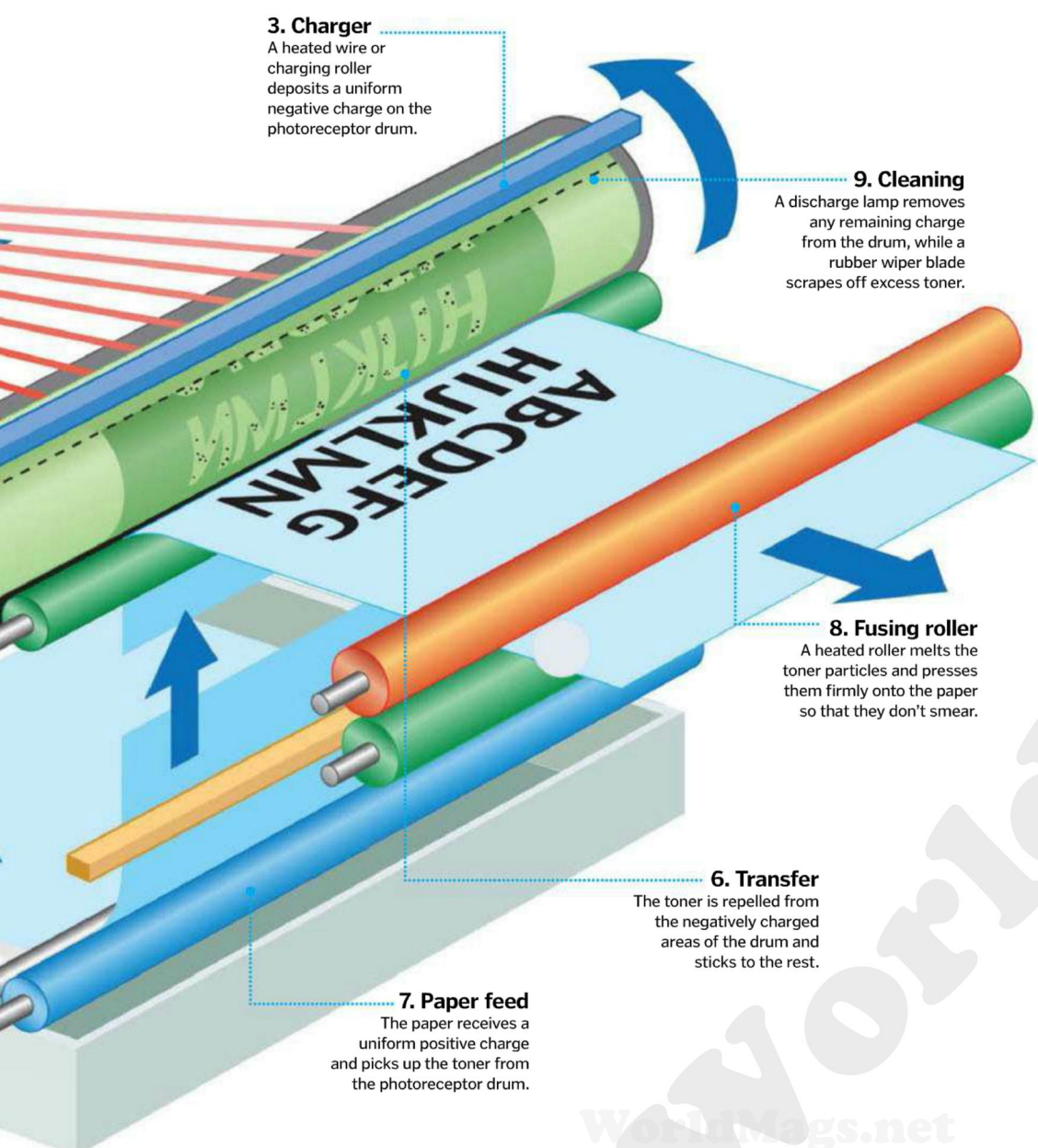
DID YOU KNOW? *Many colour laser printers add tiny patterns of almost invisible yellow dots to watermark printouts*

What is toner?

Toner is more than just dry ink. It's a precise mixture of pigment and a special polymer such as styrene acrylate copolymer or polyester resin. The polymer boasts a property known as triboelectricity – this means it generates an electric charge when it is rubbed. As the drum in the toner cartridge rotates, the toner particles are jostled against one another and become charged so that they adhere to the photoreceptor drum. The polymer is also what enables toner particles to stick to the paper. When the fusing roller heats the toner, the polymer melts and binds the pigment permanently. If you spill toner on your clothes you should only wash them in cold water; even a warm wash will lock in the stain. Different companies have their own formulations, but most 600 dpi (dots per inch) printers use toner particles of just eight to ten micrometres – which is finer than talcum powder.



With around 300 million toner cartridges thrown away every year, there is a big drive to encourage people to recycle them



3. Charger
A heated wire or charging roller deposits a uniform negative charge on the photoreceptor drum.

9. Cleaning
A discharge lamp removes any remaining charge from the drum, while a rubber wiper blade scrapes off excess toner.

8. Fusing roller
A heated roller melts the toner particles and presses them firmly onto the paper so that they don't smear.

6. Transfer
The toner is repelled from the negatively charged areas of the drum and sticks to the rest.

7. Paper feed
The paper receives a uniform positive charge and picks up the toner from the photoreceptor drum.

What's the alternative?

1 Inkjet
The most common home printers are inkjets. The printhead uses a heating element or an electric charge to propel tiny droplets of water-soluble ink onto the page. This allows cheap photo-quality prints but they are prone to smudging.



2 Dye sublimation
A cellophane ribbon, as wide as the paper, contains panels of cyan, magenta and yellow in a repeating sequence. The printhead heats the ribbon to vaporise the dye and transfer it to the paper. It's quite expensive but produces naturalistic colour.

3 Solid ink
Solid wax sticks are melted and sprayed onto an oiled drum, which then presses against the paper. This process allows for colour prints on plastic transparencies with crisp results and costs about the same as a colour laser printer.

4 Thermal
Special thermal paper that changes colour when heated completely eliminates the need for separate ink. Commonly used to print till receipts, there are also colour versions for handheld printers used with mobile phones.



5 LED printer
Similar to a laser printer, except that a fixed bar of light-emitting diodes (LEDs) illuminates the entire row at once, instead of using a scanning laser. It is generally more reliable and faster too.

© Alamy; Epson

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"Gaming PCs work by increasing the bandwidth, stability and cooling properties of the core components"

What's inside a gaming PC?

Making a console-crushing gaming PC that delivers insane visual fidelity is easier than ever. Read about how they work and take a closer look at the anatomy

Today, the gaming industry is dominated by consoles – such as the Xbox 360 and PlayStation 3 – with large install bases worldwide. However, these machines, arguably, do not deliver users with the best gaming fidelity possible at any one time, with large seven-year-plus hardware cycles leaving games developers to constantly pare back titles in order for them to run on old hardware. Essentially, the hardware is closed and restricted, only changing when a new version of the system is released.

Gaming PCs are different. Aside from being an open platform in which users can continuously upgrade individual components to ensure maximum visual fidelity and gaming performance, they arguably offer one of the best ways to play games of any platform in the world. Almost all the games a user can play on consoles are available on PC and, due to their vastly superior hardware and control methods, they can be experienced in high-definition and with optimised input (see 'Maximum control' boxout).

Gaming PCs work, put simply, by increasing the bandwidth, stability and cooling properties of the system's core components, such as the CPU, GPU, RAM and motherboard. Enlarged bandwidth is necessary so that gaming data can be relayed between components as quickly as possible, increasing the title's frame rate and therefore responsiveness. Increased speed of data transfer often requires more electrical energy and therefore heat, which, if not properly dealt with, can cause a machine to overheat. Manufacturers of gaming PC components tackle this through modifying the system's heat sinks, fans and cooling loops. Enhancements include stock coolers replaced with integrated liquid-cooling loops, cases specifically designed to maximise out-of-system airflow and high-calibre heat-dissipating materials used throughout.

Typically, however, a key stumbling block to more users taking up gaming on the PC has been the machine's construction, with prebuilt models costing a premium and the skills and tools needed to build one yourself difficult to attain for the uninitiated. That has changed massively over the last decade though, with manufacturers redesigning components, cases and wiring layouts to simplify any potential build. Indeed, far from a full day's labour with a comprehensive toolkit, a system can now be put together in a couple of hours.

Of course, assembling a PC is only half the battle for any user, with selecting the best components for the job at hand being the first task. Here we reveal the core equipment of any gaming PC build, some of the best tech currently on the market, along with some of the new, more user-friendly features.

Processor

A PC's CPU is its computational heart. Intel's Z77 platform has been designed to take advantage of existing Sandy Bridge Intel processors, which have been the standout chips of recent years. For this build we used an Intel i5-2500k, which as well as boasting good overclocking capabilities, is pretty decent value. We also applied an integrated liquid cooling loop to ensure everything stays at an optimal temperature.



Motherboard

The spine of the gaming PC, a good motherboard is essential, as you need a piece of hardware that can handle the speed and power of the system's CPU, GPU and RAM effectively. Intel's new Z77 platform offers this, especially so when built upon by MSI, which with its Z77A-GD55 motherboard has gone to extra lengths to improve cooling and stability capabilities across the board. It comes with a boatload of ports, heat sinks and software features.





Graphics card

Modern motherboards come with an integrated graphics chipset, which is good for video playback and other low-key functions, however in order to play titles such as *Mass Effect 3* and *Crysis 2* on full settings, a dedicated card should be acquired. AMD's 7000 series of cards has just been released and here we used a R7950 Twin Frozr 3GD5 GPU, which besides being ridiculously fast, has been designed with a unique fan architecture to remain super-cool and quiet when in use.



Both the K90 and M60 boast an aluminium chassis

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5 TOP FACTS
PC GAMING

Indie
1 PC gaming can boast the most vibrant 'indie' games development community of any platform, with a host of innovative titles released each month through digital download services such as Steam.

Winning
2 One of the most popular and lucrative games in the world is the PC's *StarCraft II*. Here, teams of gamers compete in international tournaments for figures upwards of $100,000.

Cheap
3 Gaming on PC has one of the lowest entry points of any platform, with even low-end desktops, laptops and netbooks capable of playing many console titles.

Evolution
4 Unlike consoles, gaming PCs can be continuously upgraded by swapping out components. This allows them to evolve over many years and keep pace with the latest gaming titles.

Output
5 Modern gaming PCs sport graphics cards capable of outputting over HDMI, allowing users to hook their machines up to large TV screens, rather than just a desktop monitor.

DID YOU KNOW? *More modern PC gaming cases position the PSU bay at the bottom of the case to improve airflow*

Anatomy of a gaming PC

The key components of a games machine explained



Random access memory
RAM may look like an insignificant part of, consisting of just a couple of small rectangular sticks, but in fact it is a central part of any machine. In gaming PCs its role is even more important, receiving and temporarily storing data for the system's CPU to process. Obviously, if a user's system's RAM isn't fast enough, or there isn't enough, then a user will experience stuttering and slowdown when playing. 6GB of RAM should be opted for ideally in any build, as demonstrated here in our choice of 8GB of Corsair's Vengeance LP memory.



Power supply unit
All these components require a fair amount of electrical energy, which needs to be supplied by a PSU. It is critical that any gaming PC carries a PSU capable of stably outputting enough juice to power all of the machine's components – especially so if a user overclocks their system – as otherwise it will suffer instability issues. We used a Corsair TX750M, as each unit is tested and qualified at 50°C (122°F) in an oven at 100 per cent load; it delivers a healthy 750W of power and features a modular cabling array.





Hard drive
Traditional disk-based hard drives are common in gaming PCs and any 5,400 or 7,200 RPM hard drive is just fine for installing and playing games. However, there have been great advances in recent years in solid-state hard drives, which aside from being almost silent (no fan) offer an order of magnitude more speed than their disk-based compatriots. We used a Corsair 128GB Force GT solid-state hard drive in this build, which offers a good gigabyte-to-cost ratio.

Maximum control

A powerful gaming PC is nothing without the means to control it

While a gamepad is fine on consoles, to maximise the fluidity of control on a PC a good keyboard and mouse are crucial. Luckily, dedicated gaming peripherals are now manufactured by many companies, offering better speed, accuracy and durability.

Corsair's Vengeance series of peripherals epitomises these, offering unique features and top-end build quality. For example, the K90 gaming keyboard comes with Cherry MX Red mechanical keyswitches for speed and accuracy, 100 per cent anti-ghosting and a 20-key rollover on USB. These features are vital when gaming as every second can make a difference.

Equally impressive is the M60 gaming mouse, which comes with an integrated 5,700dpi sensor and Omron switches. The sensor is first-class, offering a huge improvement in accuracy over that of a standard mouse. Both the M60 and K90 are made of aluminium, which gives them a lightweight and smart finish.



© MSI

Overclock master

Overclocking used to be a 'dark art', requiring pro tools and techniques. But today speeding up PC components couldn't be simpler

One of MSI's Z77A-GD55 motherboard's best features is its overclocking-friendly design, with large, integrated heat sinks, a super-ferrite choke, highly conductive polymerised capacitors and generally industrial build quality.

Of course, many motherboards that have come before the Z77A-GD55 sported similarly impressive hardware, however most of them still relied on the user opening the PC's BIOS menus and tampering with a series of complex features, altering voltages and timings in a trial-and-error manner.

Handily, MSI has gone a long way to negate the need for any BIOS wizardry by introducing its Control Center II and OC Genie II software. These are user-friendly programs that anyone can run in their desktop environment to enable real-time overclocking, allowing for – in optimal conditions – an over 30 per cent performance increase. Further, because the overclocking can be done on the fly, users can discover their system's optimal configuration far quicker than before, with no endless reboots needed to achieve a stable overclock.

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"To make a tri-gate transistor, photoresist is applied plus a chemical to etch into unwanted silicon"

How do computers stay cool?

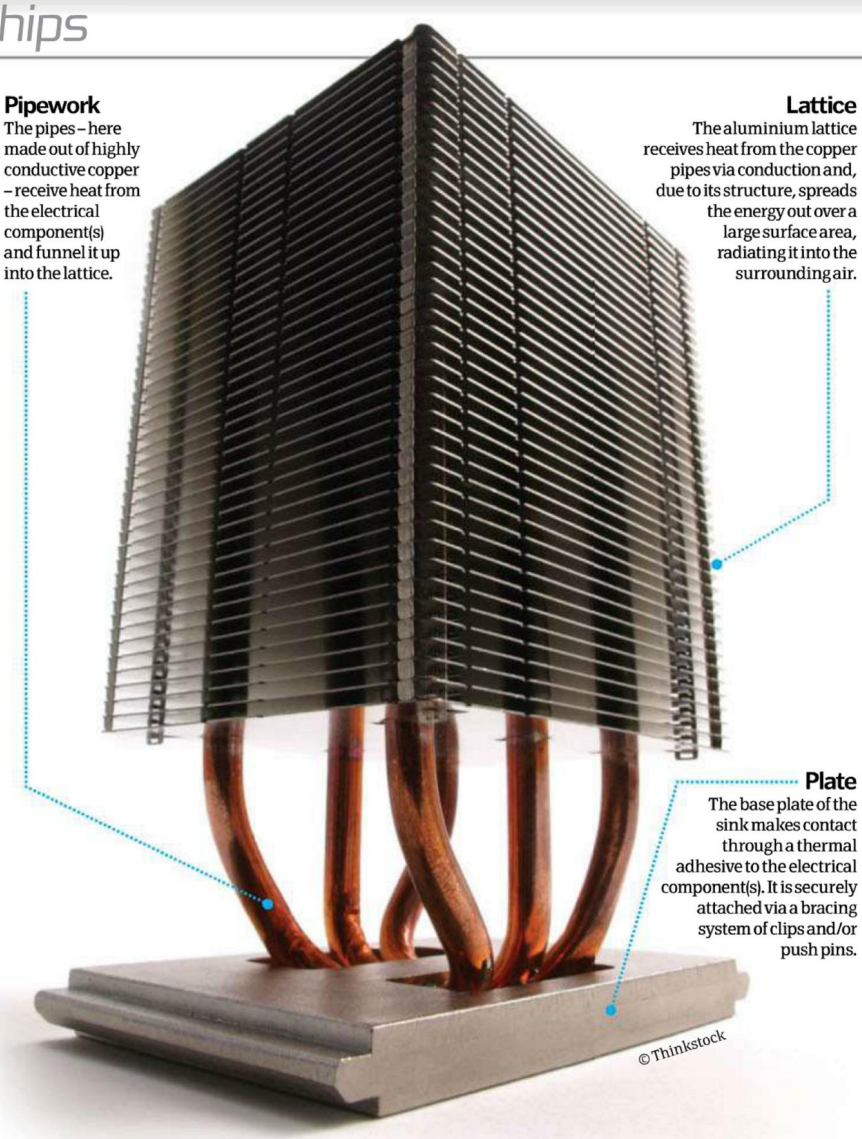
Learn how heat sinks help a computer reach its full potential

Heat sinks are passive cooling components commonly found in PCs. They consist of a series of metal plates, pipes, pins and lattices that work together to absorb heat from electrical components through conductivity then dissipate it into the environment.

Conduction, which is the central operating principle of heat sinks, occurs when two objects with different temperatures are placed in contact with each other. When they touch, the hotter object's faster-moving molecules transfer a portion of their energy to the colder object's less-active molecules.

Not surprisingly, for conduction to take place optimally, the two objects must be made out of a material that is a good conductor. Metals, for the most part, are very effective and, as such, form the base material for almost all heat sink devices. Aluminium alloys and copper are probably the two most commonly used metals on commercial heat sinks as they offer a favourable thermal conductivity-to-cost ratio.

If we take a computer's central processing unit (CPU) as an example component, its mounted heat sink operates by attaching itself to the CPU's small surface area (ie the top of the chip) and then transfers the generated heat away via a series of pipes into a lattice. The lattice, due to its considerable surface area, allows for a balanced and more rapid radiation of the heat into the surrounding system, which enables the processor to remain at a stable and efficient operating temperature.



Pipework
The pipes – here made out of highly conductive copper – receive heat from the electrical component(s) and funnel it up into the lattice.

Lattice
The aluminium lattice receives heat from the copper pipes via conduction and, due to its structure, spreads the energy out over a large surface area, radiating it into the surrounding air.

Plate
The base plate of the sink makes contact through a thermal adhesive to the electrical component(s). It is securely attached via a bracing system of clips and/or push pins.

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CAPTCHA technology: human vs computer

We investigate the digital test with designs on distinguishing Joe Bloggs from joke blogs

CAPTCHA technology, or Completely Automated Public Turing test to tell Computers and Humans Apart, is waging war on spam bots blagging their way into our inboxes. But how can these randomly generated, cryptic codes hope to get the better of this sinister cyber-culture?

CAPTCHAs rely on the fact that computers struggle to decode human languages as they are too irregular. So couple an unusual word, image or number puzzle with some design morphery and, in theory, the bots should be flummoxed. But for every randomly generated test follows code designed to crack it. The recent digitisation of literature, from ancient scriptures to back copies of your local newspaper, using optical character recognition (OCR), unwittingly created a computer-proof directory of words already being put to use. Google's reCAPTCHA project works with OCR castoffs to pair up these digitally distorted dregs, then further warp them, to guarantee the confusion of those unsavoury programs intent on infiltrating private online space.



Distortion
CAPTCHAs often take normal words and morph them into unfamiliar shapes. Both visual and audio tests are used.

Patterns
The human mind can pick out patterns a lot more easily than a computer can.

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How silicon chips are made

Follow our step-by-step guide to how computer chips are manufactured



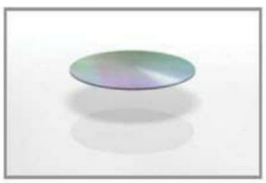
1. Sand

To kick off the process silicon is harvested from raw sand. Silicon is used as it is an excellent conductor and insulator of electricity.



2. Ingot

The silicon is purified by melting it down and leaving it to cool. The result is a continuous, cylindrical crystal lattice known as an ingot.



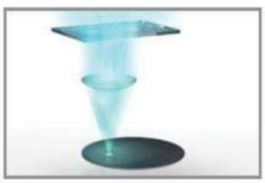
3. Cut and polish

The ingot is cut into silicon discs called wafers (1mm/0.04in thick and 300mm/11.8in in diameter). These wafers are then polished.



4. Photoresist

A liquid known as photoresist is poured onto the wafer, which is sensitive to certain frequencies and resistive to particular chemicals.



5. Harden

The photoresist is hardened, with parts exposed to UV light, making it soluble. This process leaves a photoresist pattern on the wafer.



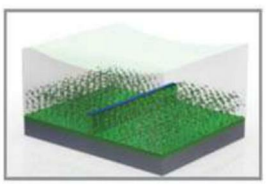
6. Ions

The patterned wafer is bombarded with a beam of ions. The areas not covered with photoresist are made either conductive or insulating.



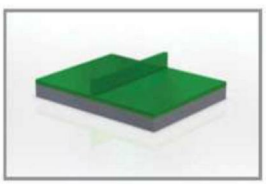
7. Removal

Next the photoresist is removed leaving a wafer with a pattern of ion-rich areas in which transistors can then be generated.



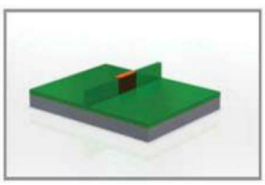
8. Etch

To make a tri-gate transistor, photoresist is applied plus a chemical to etch into unwanted silicon, leaving a raised fin.



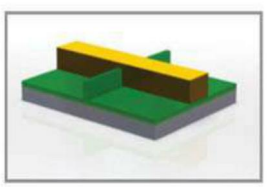
9. Chemical

The fin's top layer of photoresist is then removed to leave a tall, thin silicon fin that will eventually contain the transistor's channel.



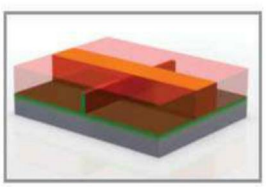
10. Gate

A thin silicon dioxide layer (red) is created by depositing the wafer in an oxygen-filled tube furnace. This acts as a temporary gate dielectric.



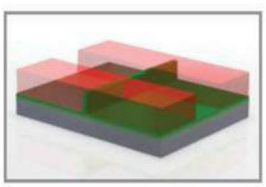
11. Electrode

A temporary gate electrode is made via the temporary gate dielectric. The electrode is fashioned from polycrystalline silicon (yellow).



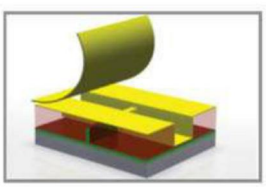
12. Insulate

The entire wafer is oxidised so a silicon dioxide layer forms (transparent red), insulating the transistor from other elements.



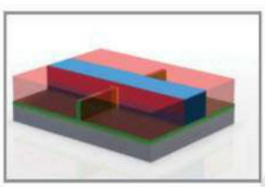
13. Sacrifice

The temporary gate electrode and gate dielectric are removed. This clears the way for the permanent gate to be added.



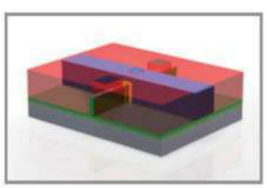
14. ALD

Molecular layers (yellow) are deposited onto the wafer using atomic layer deposition (ALD). Unwanted regions are etched away.



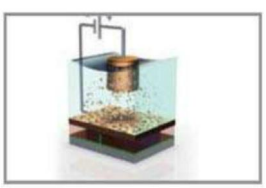
15. Metal

Lithography is used to make a metal gate electrode to replace the temporary gate. This vastly improves transistor performance.



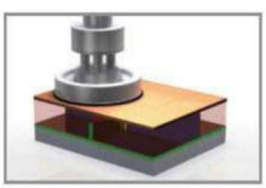
16. Holes

Three holes (red) are etched into the insulation and filled with copper. Via the copper the transistor can be connected to others on the wafer.



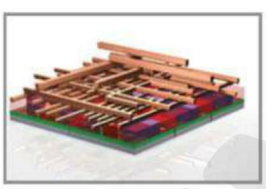
17. Electroplating

The entire wafer is placed into a copper sulphate solution. The copper's ions are then adhered to the transistors via electroplating.



18. Settle

Once removed from the solution, the copper ions are left to settle on the wafer's surface, creating a super-thin layer of the metal.



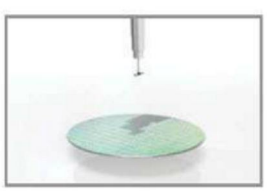
19. Clean

When the layer has settled, excess material is mechanically polished off the surface of each transistor to form a specific pattern of copper.



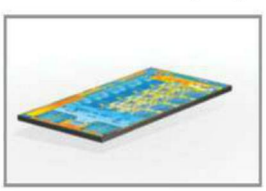
20. Wired

Circuit lines over several layers are made to link the wafer's transistors together. The wiring's design is determined by the chip's function.



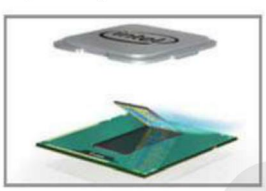
21. Die

The finished chips are tested by being fed testing patterns and recording their responses. The wafer is cut into pieces called dies.



22. Selection

The dies that responded correctly to the pattern tests are then selected ready for packaging. Faulty dies are discarded.



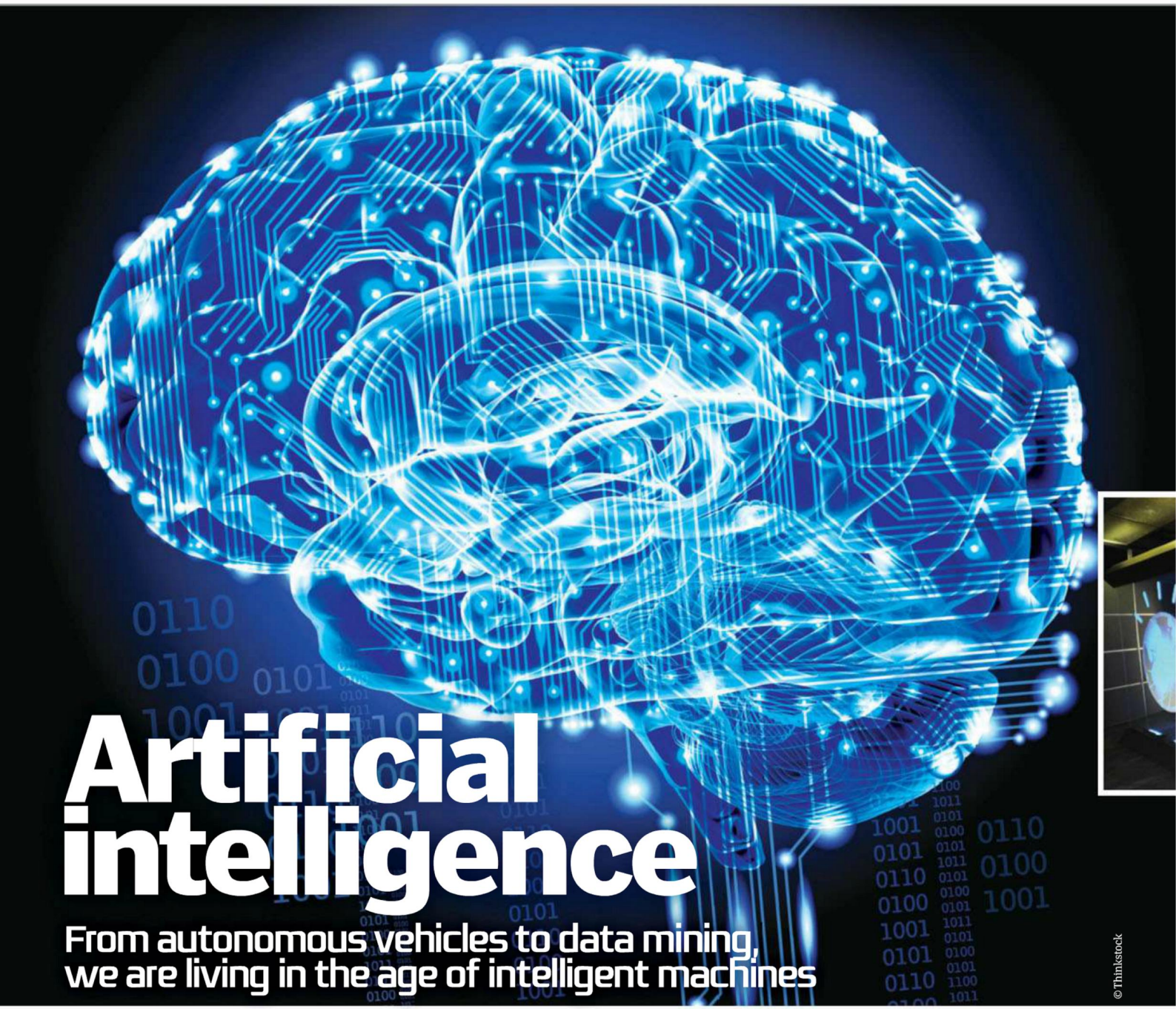
23. Combine

Finally, the package substrate, die and heat spreader are combined to form a complete processor, which is then boxed and shipped for sale.



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Artificial intelligence

From autonomous vehicles to data mining, we are living in the age of intelligent machines

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"What is artifacial inteligance?" you ask Google. To which it replies, "Did you mean artificial intelligence?" Of course you did. Meanwhile, in the 0.15 seconds it took you to realise your own stupidity, an intelligent machine has assembled 17,900,000 results for your consideration – including video, audio, historical records and the latest headlines – ordered by relevance and reliability. 20 years ago, this type of intelligence would have been the stuff of science fiction, but now we call it 'technology'.

Artificial intelligence began over 60 years ago as a philosophical question posed by the brilliant English mathematician Alan Turing: "Can machines think?" In 1955, the words 'artificial intelligence' first appeared in print in a proposal for a summer academic conference to study the hypothesis that "every aspect of learning or other feature of intelligence can in principle be so precisely described that a machine can be made to simulate it".

At its core, the science of AI is the quest to understand the very mechanisms of intelligence. Intelligence in humans or machines can be defined as the ability to solve problems and achieve goals. Computers, it turns out, are the ideal machines for the study of AI, because they are highly 'teachable'. For half a century, researchers have studied cognitive psychology – how humans think – and attempted to write distinct mathematical formulas, or algorithms, that mimic the logical mechanisms of human intelligence.

Machines have proven extraordinarily intelligent, with highly logical problems requiring huge numbers of calculations. Consider Deep Blue, the chess-playing computer from IBM that beat grandmaster Gary Kasparov using its brute processing strength to calculate a nearly infinite number of possible moves and countermoves.

5 TOP FACTS EVERYDAY AI

Google
1 When you type a search term into Google, you are tapping the collective knowledge of over 30 billion webpages. But it's proprietary algorithms that sort through the content.

Logistics
2 AI software is what keeps the supply chain running smoothly. Computers track inventory, schedule manufacturing, and procure new parts from suppliers.

Fraud detection
3 Credit card companies use intelligent pattern recognition software to identify any abnormal purchases. It can put a hold on the card without any human intervention.

Virtual assistants
4 An increasing number of websites use virtual 'chatbots' to answer frequently asked questions and help customers navigate their site.

GPS navigation
5 More and more cars feature Bluetooth-enabled GPS navigation systems. Simply say your destination and the real-time mapping software will determine the best route.

DID YOU KNOW? *Colossus, the first electronic computer, was built in 1943 by British engineers to crack coded Nazi transmissions*

IBM's Watson

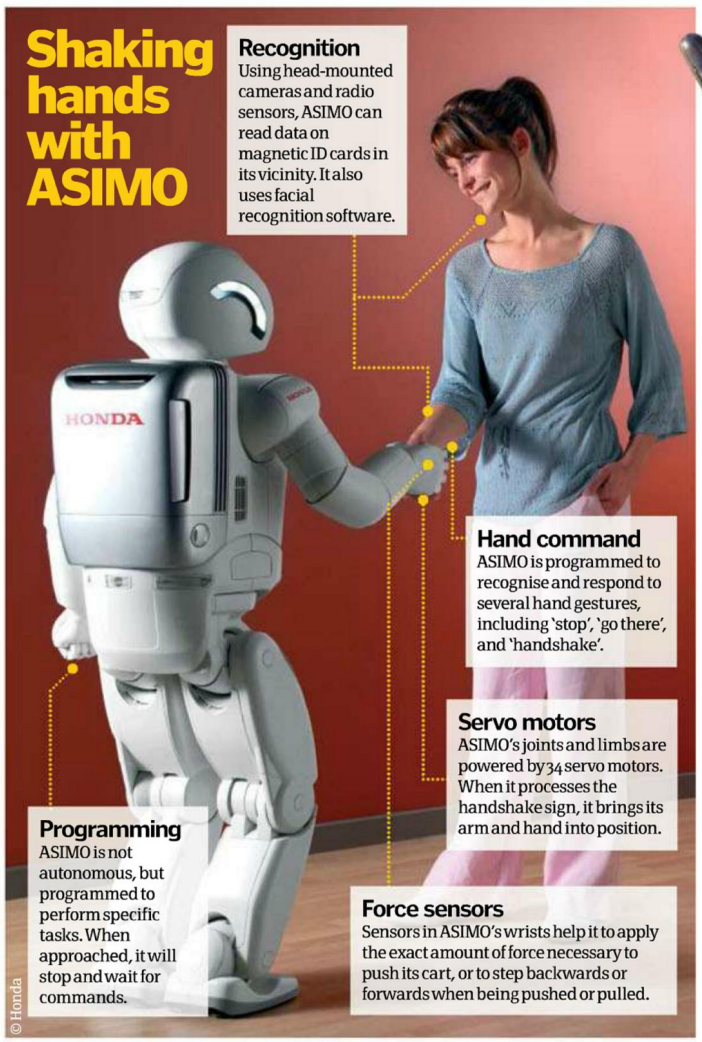
In February 2011, an IBM supercomputer named Watson trounced two previous champions of the US trivia quiz show *Jeopardy!*. Watson parsed natural language questions fast enough to beat the quickest human minds. IBM researchers preloaded the computer with hundreds of millions of pages of data, then armed it with algorithms for searching and 'reading' text – separating subjects, verbs and objects. But this was much more than a super-powered Google search. Watson used advanced algorithms to 'reason' which of its millions of hypothetical answers was most likely to be true. The 'face' behind the *Jeopardy!* podium was backed by a roomful of servers, comparing results in fractions of a second until the computer had enough statistical confidence to buzz in. Watson technology is already being considered as the brains behind an automated physician's assistant.



The IBM Watson supercomputer

© IBM

Shaking hands with ASIMO



Recognition
Using head-mounted cameras and radio sensors, ASIMO can read data on magnetic ID cards in its vicinity. It also uses facial recognition software.

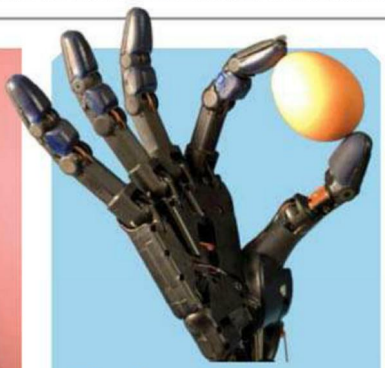
Hand command
ASIMO is programmed to recognise and respond to several hand gestures, including 'stop', 'go there', and 'handshake'.

Servo motors
ASIMO's joints and limbs are powered by 34 servo motors. When it processes the handshake sign, it brings its arm and hand into position.

Programming
ASIMO is not autonomous, but programmed to perform specific tasks. When approached, it will stop and wait for commands.

Force sensors
Sensors in ASIMO's wrists help it to apply the exact amount of force necessary to push its cart, or to step backwards or forwards when being pushed or pulled.

© Honda



Robotics and AI

The world's most advanced robots navigate their environments with sensors that mimic our senses of vision, hearing, touch and balance.

The lifelike androids designed by Hiroshi Ishiguro at the Intelligent Robots Laboratory use real-time facial recognition software to mimic the facial movements of the 'controller'.

Walking robots like ASIMO are equipped with an internal gyroscope and speed sensor to help it maintain balance, even when shoved. Infrared and ultrasonic sensors are used to gauge the distance of the floor and the speed and path of approaching objects. Sensors in hands and feet help it 'feel' the six axes of force – up/down, left/right, forwards/backwards – and the degree of force applied.

Alternatively, consider the everyday examples of astonishing AI, like the GPS navigation systems that come standard in many new cars. Speak the address of your destination and the on-board computer will interpret your voice, locate your precise location on the globe and give you detailed directions from Moscow to Madrid. Or even something as 'simple' as the spell check on your word processor, casually fixing your typos as you go.

And then there are AI machines that go far beyond the everyday, like robots. Today's most extraordinary robotic machines are much more than logically intelligent; they're also physically intelligent. Consider Stanley, the 100% autonomous vehicle that barrelled through the Mojave Desert to win the 2005 DARPA Grand Challenge. Stanley used GPS data to pinpoint its location, as well as laser-guided radar and video cameras to scan the distance for obstacles in real-time. Internal gyroscopes and inertial sensors feed constant streams of data into the on-board computer to control steering and acceleration.

The Honda ASIMO (Advanced Step in Innovative MObility) robot grabbed the world's attention with its human-like walk, a feat of intelligent engineering. ASIMO uses infrared and ultrasonic sensors to gauge distances from floors, walls and moving objects, and constantly adjusts its balance and motion with 34 high-precision servo motors. ASIMO's processors are so lightning-fast, you can shove the robot sideways in mid-stride and it will 'instinctively' throw its weight onto an outside foot to right itself.

Perhaps the greatest achievements of artificial intelligence over the past half-century have been illustrated by the way that machines ▶

AI FIRSTS Where artificial intelligence all began and where it's heading next...

400 BCE – Mechanical dove
Archytas of Tarentum constructs a wooden dove that can flap its wings and even fly.

5TH CENTURY BCE – Aristotle's logic
Aristotle defines syllogistic logic – how a single conclusion is drawn from two premises.

15TH CENTURY – Spring-driven clocks
These clocks and watches are the world's first mechanical measuring machines.

13TH CENTURY – Lullian machine
A Spanish monk creates a machine that draws conclusions from different paired symbols.

1642 – Pascal's calculating machine
The wooden box with a metal crank can handle both addition and subtraction.

1801 – Punch cards
A French silk weaver automatically controls a loom using a series of punch cards.

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"We are teaching machines to rely less on pure logic"

▶ can intelligently process information. Google is just one example of intelligent information technology that can parse obscene amounts of data into useful information.

Intelligent cell phone networks bounce packets of voice data along the most efficient path. Logistics software is the engine of global business, calculating the most efficient and profitable way to procure supplies, manufacturer and ship products around the world.

Credit card companies use intelligent software to analyse the buying patterns of millions of cardholders and identify the subtle red flags that signal fraud or theft. In the information age, we rely on these intelligent machines to make sense of streams of seemingly random data.

As processing power continues to multiply, we are coming closer to answering Turing's original question: "Can machines think?" We are teaching machines to rely less on pure logic and more on probabilities and experience, what we might call 'intuition'. And they are fast learners...

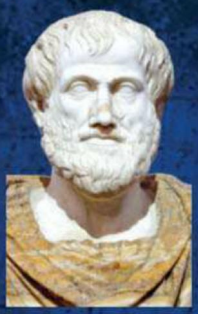


ASIMO uses complex tech to help it maintain balance

© Honda

INSIDE THE AI BRAIN

The human brain is a profoundly complex machine. What we regard as simple common sense is actually a combination of stored knowledge, logical reasoning, probability and language interpretation. In the last 50 years, AI researchers have made strides towards building a machine that can truly 'think'



LOGIC

Dating back to the days of Aristotle, philosophers have attempted to map and define the logical processes by which we make decisions. Rather than living life on a whim, the 'rational actor' makes choices and takes action based on evidence and inference, cause and effect. If a machine is to become a rational actor, it must be programmed to recognise that if A and B are true, then the only logical conclusion is C. The challenge of AI is to create mathematical models for logical processes that the machine can use to make reasonable decisions based on evidence and probability.

LANGUAGE



© IBM

Human beings have many ways of learning, such as listening, watching, reading and feeling. The only way for a machine to learn is through language. Computer programming languages are grounded in logic. Consider the most basic if/then statement: If X is greater than 1, then go to Y. With greater processing power, computers are being taught to interpret natural language – the way humans communicate. IBM's Watson computer can read natural text because it was programmed to parse sentences for subject, verb and object and compare those entries with its vast database of knowledge.

SEARCH AND OPTIMISATION

Google is an example of artificial intelligence – if it was only a search engine, it would randomly assemble a list of every webpage that included your term. But Google programmers have armed the engine with algorithms that help it optimise searches to retrieve the most relevant matches first. AI machines use the same methods to search for the most logical response to environmental data (don't run into that table) or direct queries (what's the balance on my bank account?). They're programmed to use heuristics – short cuts – to eliminate the least-probable search paths.

Google

1821 **Difference Engine No 1**
Charles Babbage envisages a complex calculating machine.

1850s **Boolean algebras**
George Boole uses syllogistic logic to reduce maths functions to two symbols: 0 and 1.

1889 **Electric tabulating system**
Herman Hollerith devises a way to mechanically record data.

1910 **Principia Mathematica**
Work the first to derive mathematical truths from a set of axioms using symbolic logic.

1921 **'Robot' coined**
Sci-fi play is the first to call automatons 'roboti', Czech for 'forced labourers'.

1936 **Turing machine**
Polymath Turing describes his 'machine', a theoretical device that establishes the logical foundation for computer science.

1943 **Cybernetics**
Studies help to understand machine learning.

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DID YOU KNOW? *IBM's Watson runs on 90 servers, with the combined brainpower of 2,880 POWER7 microprocessors*

PROBABILITY

Humans are likely to base decisions on the probability of something being true, given past experiences and the current conditions. AI machines can be programmed to reason in similar ways. Computers are excellent statisticians, and with the right algorithms, they can quickly make billions of calculations to decide which answer/action is most likely to produce the desired result. As new evidence is presented, AI machines use Bayesian probability to overlap the new set of probabilities over existing calculations.





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ALGORITHMS

Algorithms are the bits of programming logic that instruct the computer how to do something. A good example is the minimax algorithm that helps a chess-playing computer like IBM's Deep Blue decide its next move. Minimax algorithms assign a value to each position and piece on the board and search through all possible moves to decide which delivers the best results. To optimise the search, Deep Blue only considered the next 12 moves instead of every possible move and countermove, until checkmate.



REASONING

It was once believed that the AI brain could only reason according to strict rules of logic. Question-answering computers like IBM's Watson are proof that machines can be taught to reason on higher levels. Watson begins with straight logic: searching its vast database of knowledge for keywords in the question. But then it uses much more complex algorithms to identify related concepts and make the kind of intuitive connections we call 'experience'. Probability is a huge component of higher-level machine reasoning, using unprecedented processing power to give the most likely answer from a nearly limitless range of knowledge.



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How human are you?

Alan Turing was a British mathematician and philosopher who is considered by many to be the father of AI and modern computer science. In his 1950s paper Computing Machinery And Intelligence, Turing posed the question "Can machines think?" Admitting that 'thought' is such a vague and subjective term, he decided to answer a different question: "Can a machine successfully imitate the way humans interact?" He proposed a game or 'test' in which subject A was human, subject B was a machine and subject C – another human – had to distinguish between the two using text-based questions and answers. Turing himself believed that with enough storage capacity and processing power, a machine could successfully beat the test. This Holy Grail of AI is being pursued by designers of interactive 'virtual assistants' and question-answering supercomputers.

Shown below are answers from the Loebner Prize, an annual competition to determine how human a program can be. In terms of conversation, we clearly still have a little way to go...

	ROBOT ANSWER	HUMAN ANSWER
Do you like baseball?	What is a baseball team?	Yes!
When were you born?	I have been born?	1978
What kind of food do you like?	Well, what kind of band is it?	I'm partial to anything, really
Have I offended you?	I just met you. It's kind of hard to develop love	No, not at all!
What is your favourite book?	Led Zeppelin	Lord Of The Flies

1949 – Computer chess
Claude Shannon proposes the functions for programming a computer to play chess.

1955 – 'Artificial intelligence' invented
John McCarthy uses the phrase in a proposal for a conference on machine learning.

1956 – First AI program
The Logic Theorist is the first program written to mimic the human thought process.

1979 – Autonomous robot
The Stanford Cart successfully navigates a room full of obstacles using sensors and software.

1997 – Deep Blue
World chess champion Gary Kasparov loses to the IBM supercomputer.

1997 – Google
The web's most influential piece of AI programming is launched.

2011 – IBM Watson
The DeepQA supercomputer uses language analysis algorithms to beat two former *Jeopardy!* champions.

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HOW IT WORKS

GADGETS

The coolest kit explained



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Taking the humble timepiece to a new level

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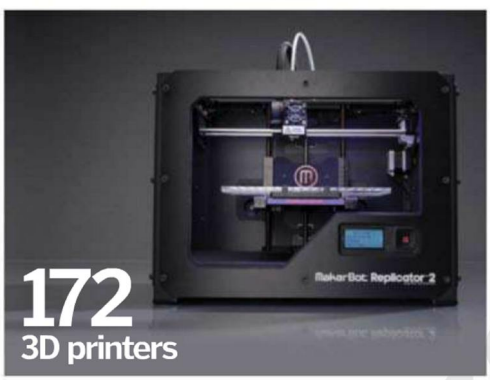
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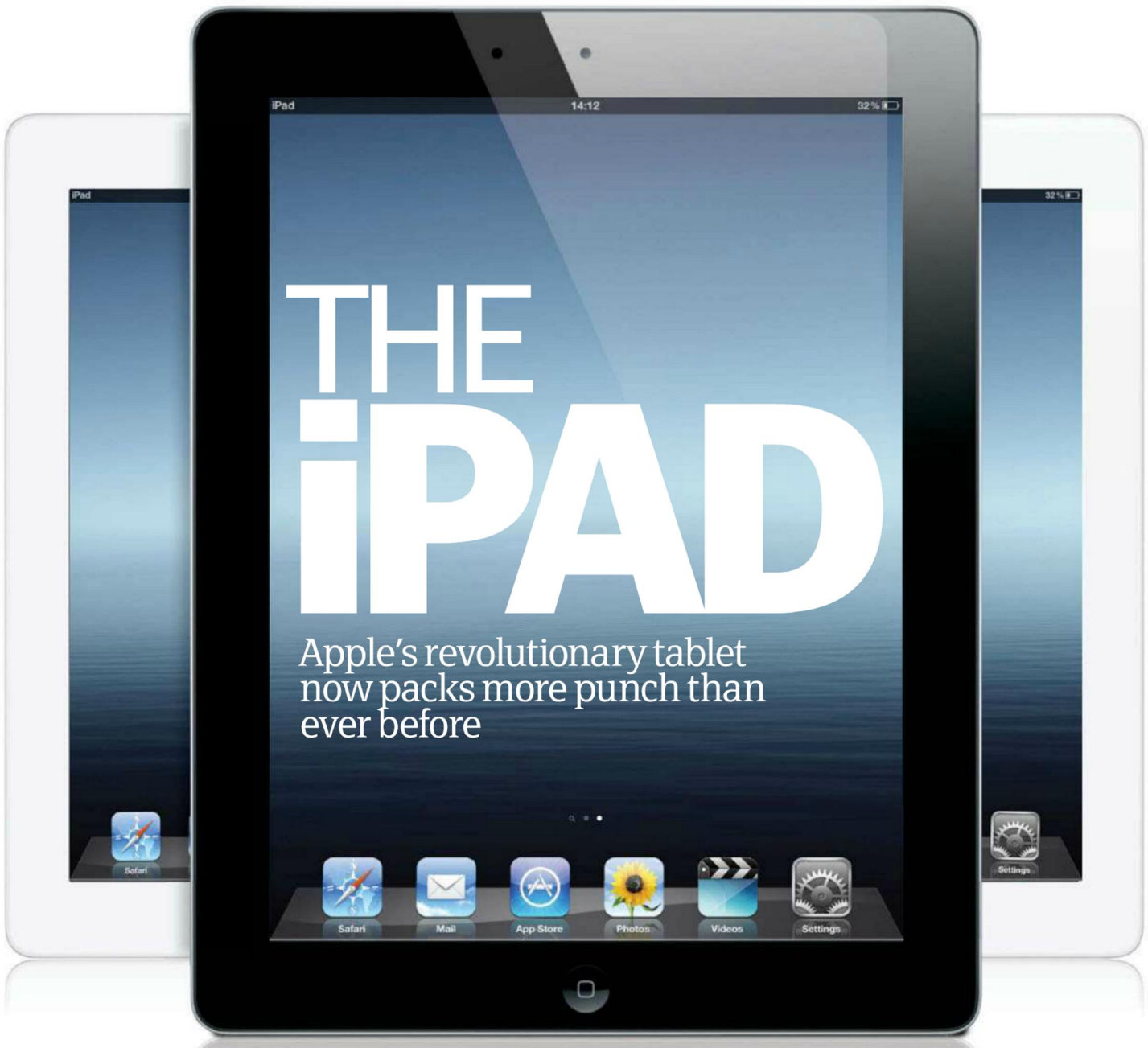
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How home entertainment has evolved

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In the world of tablet computing there is one clear leader and that is Apple and the company's incredibly popular iPad. The latest iPad is the tech king's fourth generation of its full-size tablet computer and it has built on the considerable success of its predecessors with some extremely advanced technology.

For anyone who doesn't know, a tablet computer is one that can be held in the hands and manipulated with taps, swipes and other multitouch gestures made by the fingers. Apple's new iPad is no different, running on the company's proprietary operating system, iOS.

The biggest feature is a new screen which packs a whopping 2,048 x 1,536 resolution into a 24.6-centimetre (9.7-inch) screen. This amounts to 1 million more pixels than the average HD TV. Apple has had to do all kinds of technical wizardry to make this screen possible, including dealing with pixels in a totally new way.

Pixels are what make up the display. Each pixel consists of three colours, and the level of light in each colour makes up the finished colour that your eye sees. When all are lit fully you see white, for instance, and when none are lit you see black. There are four times as many pixels in the new iPad as there were in the previous one and to make sure that each one gets the correct signal to display the right colour at the right time, they have had to lay them in a specific way on a different plane from the signal.

This is a breakthrough technology that no other display currently uses and you can really tell when you see the crispness of text and the richness of colours. The screen has been labelled a 'Retina' display because at the standard viewing distance of around 30 centimetres (12 inches) it is impossible for the eye to discern individual pixels. Because of this, to the human eye everything looks smooth –

KEY DATES
iOS HISTORY

1976 – Steve Jobs and Steve Wozniak start Apple Computer, Inc, making PCs from a garage in California.



2008 – Apple sets up the App Store through an update to its syncing software iTunes.

2010 – The first iPad tablet computer is launched and sells 300,000 units on the first day alone.

2012 – Apple announces that it has exceeded 25 billion apps downloaded from its App Store.



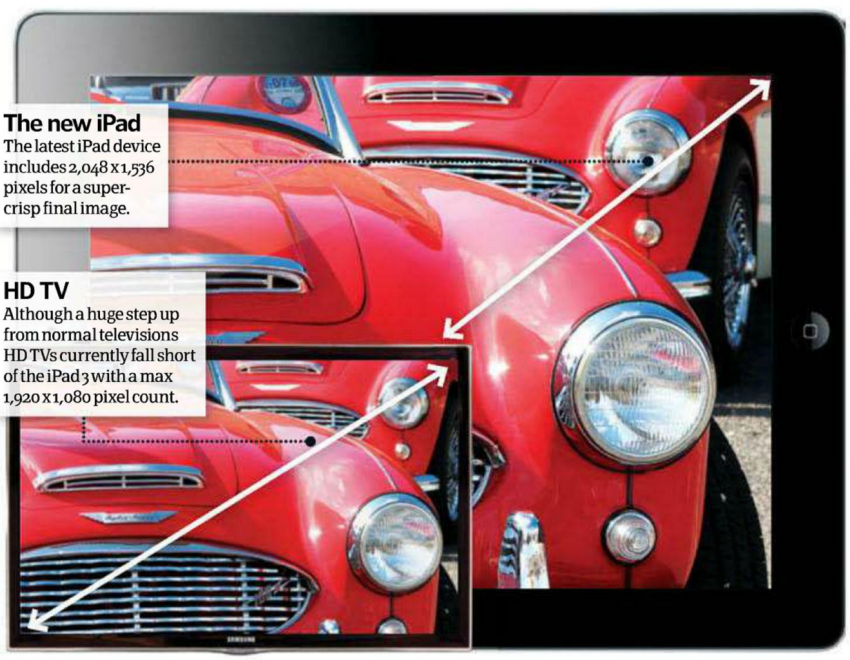
2013 – Just over a year later, Apple announces that the 50 billionth app has been downloaded.

DID YOU KNOW? *Apple's market cap ($547bn) is greater than the GDP of Belgium, Sweden, Saudi Arabia and Taiwan*

How a Retina display works

A closer look at the screen that packs a pixel punch

Apple's Retina display works by packing so many pixels close together that the human eye is unable to distinguish between them. There is a secondary variable in making this happen in as much as you have to observe a standard viewing distance, which in this case is 30 centimetres (12 inches) or so. Should you creep closer to the display you may begin to discern individual pixels. The resolution of the screen is 2,048 pixels along the longest edge and 1,536 across the shortest. This is far more than most HD TVs which average 1,920 x 1,080. The increase in pixels and their density together allows for much sharper images. The downside is that it is far more susceptible to flaws and requires much more power. Apple has attempted to counter these issues, however, as explained later in the feature.



The new iPad
The latest iPad device includes 2,048 x 1,536 pixels for a super-crisp final image.

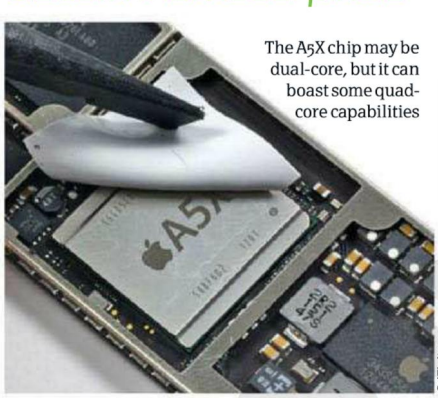
HD TV
Although a huge step up from normal televisions HD TVs currently fall short of the iPad 3 with a max 1,920 x 1,080 pixel count.

as it does in print, which also has a very high resolution.

Other advances in the more recent iPads are a 70 per cent bigger battery, and by bigger we mean capacity, not size (though the third-generation iPad is marginally thicker than its predecessor). There is also a new camera which has some impressive technology coupled with a five-megapixel sensor. The same camera is capable of shooting 1080p video. In terms of pure computing power the iPad uses a dual-core chip with integrated quad-core graphics, which has been dubbed an A5X chip. Apple builds its own custom silicon processors for handheld devices. This allows it to optimise the way the tablet works, controlling both the software and the hardware.

There is also an increase in the amount of RAM in the new iPad; it now packs 1GB and comes with different storage options – 16GB, 32GB, 64GB and 128GB – as well as coming in both Wi-Fi and 4G variations.

"At the standard viewing distance of around 30cm (12in) it's impossible for the human eye to discern individual pixels"



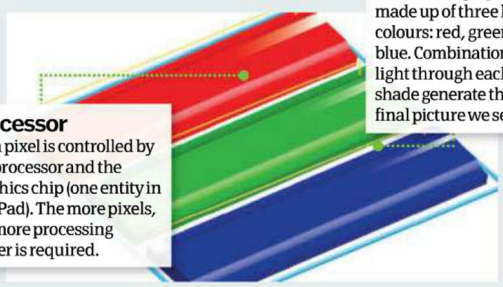
The A5X chip may be dual-core, but it can boast some quad-core capabilities

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PIXEL BREAKDOWN

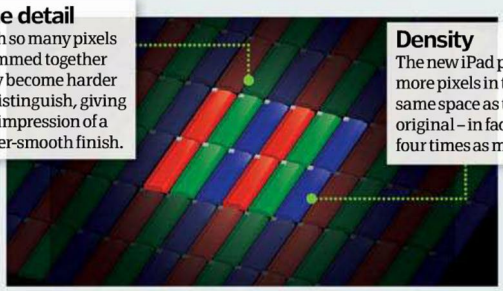
So how do pixels work on a microscopic scale?

RGB colours
Here is a single pixel, made up of three light colours: red, green and blue. Combinations of light through each shade generate the final picture we see.



Processor
Each pixel is controlled by the processor and the graphics chip (one entity in the iPad). The more pixels, the more processing power is required.

Fine detail
With so many pixels crammed together they become harder to distinguish, giving the impression of a super-smooth finish.

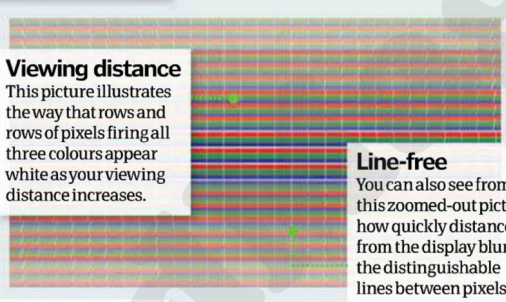


Density
The new iPad packs more pixels in the same space as the original – in fact, four times as many.



Power hog
The new iPad's screen needs lots of power. Apple has had to raise battery capacity by 70 per cent to cope.

Super signal
To prevent problems with signals reaching so many pixels, Apple engineers had to place the pixels on a different plane, above the signal path.



Viewing distance
This picture illustrates the way that rows and rows of pixels firing all three colours appear white as your viewing distance increases.

Line-free
You can also see from this zoomed-out picture how quickly distance from the display blurs the distinguishable lines between pixels.

Text in focus
Rendered text on the new display is razor sharp meaning that words can be read at smaller sizes.



Real curves
On a lo-res display you can make out the pixels along curved edges, but on a hi-res screen this isn't possible.

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"The A5X chip is 36 per cent larger than the one in the iPad 2"

4G TECHNOLOGY

4G is the next generation of cellular mobile communications. It supersedes 3G offering speeds that could reach ten times that of current capabilities

The question that everyone wants to know is: just how fast is 4G? Well, standard 3G connections today offer around 7.2Mbps although in reality most of us won't experience much more than 1-2Mbps. True 4G technology could potentially increase these speeds significantly to beyond 100Mbps, but there are several competing technologies that offer varying pros and cons. Below we take a closer look at the main 4G contenders...

LONG-TERM EVOLUTION (LTE) 300MBPS

This is the most popular of the technologies currently planned for widespread rollout. It is behind most of the planned strategies in the US and the UK. Scientific theory suggests that there could be a top speed as high as 300Mbps for LTE, although the current speeds being achieved in the US – where some 4G LTE services have gone live – are around the 6-12Mbps mark. While not getting anywhere near the theoretical speeds it does offer a huge uplift in the real-world speed, especially when you consider that this is a mobile service.

WiMAX 128MBPS

This technology, while also offering a bumper speed of around 128Mbps, isn't particularly popular, with no UK operators as yet planning to use it and only one US carrier – Sprint – adopting it. Sprint has claimed that its real-world speeds will reach the 3-6Mbps mark.

HSPA+ 21MBPS

This technology can't offer as much speed as LTE but has become a popular alternative as the upgrade cost is far cheaper and the implementation is far simpler. HSPA+ has been in use in the US by operator T-Mobile which claims that real-world speeds are around the 1-7Mbps mark and that eventual top-end speeds could reach 21Mbps. In the UK, Three Mobile will be using this technology through a dongle called Huawei E367. Much like the advance to 3G, 4G rollout will be taking place over the next few years. America is already readying its networks with some live now. The UK, however, is behind the times waiting for the two bands of spectrum to be auctioned off by regulatory body Ofcom.





APPLE'S A5X CHIP

Apple develops its own processors for its mobile devices. This is because Apple can optimise the performance of the chip in order to suit the device in question.

The new iPad is a perfect example of this in action with a dual-core chip that has quad-core graphics. It's no coincidence that the quadrupling of graphical processing coincides with a custom-built quad-core graphics processor. It has been specifically designed to make sure the iPad screen is fed with data in a timely fashion. Each of the processing tasks for the graphics is now split into four parts meaning that four times as many tasks can be completed in a time that is snappy enough to deal with the games, pictures and apps that customers want to run.

The dual-core portion of the processor is reserved for purely computational tasks and having two cores means the workload is halved across two processors, making for a speedy experience. Interestingly the A5X chip is 36 per cent larger than the one included in the iPad 2.

Inside the iPad

So what exactly makes up the world's top-selling tablet?



Glue
The screen is glued to the rest of the device so removing it is a case of heating the glue up and then using suction to prise the two elements apart.

Toshiba NAND memory
The iPad ships with either 16GB, 32GB or 64GB of memory. It's incredible how such a large amount of storage can be packed into so small a space.

RAM
RAM is built onto the A5X chip and has been doubled from 512MB to 1GB. This provides the random access memory needed to run apps smoothly.

ON THE MAP



Who's using 4G to date?

1 Perth, Australia
2 Bangladesh
3 Belgium
4 Cameroon
5 Canada
6 Fiji
7 Ghana
8 Jamaica
9 Japan
10 South Korea
11 Nigeria
12 Norway
13 Panama
14 Peru
15 Russia
16 South Africa
17 Sweden
18 Taiwan
19 USA

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WHO'S WHO?



SIR JONATHAN IVE

Apple senior VP of product design (born in 1967)

Ive is responsible for the design of all of Apple's recent products starting with the iMac in 1998. He went on to design such iconic products as the iPod, iPhone and all iPad models.



"I discovered at an early age that all I've ever wanted to do is design"
Sir Jonathan Ive

DID YOU KNOW? *Apple sold out of pre-orders for the iPad 3 in less than a week*

Front-facing camera
Apple labels the front-facing camera as a FaceTime camera as it is primarily used with its FaceTime video chat app.

Bespoke connectors
Apple designs everything inside the iPad with the same care as it does outside, so all connectors are tailored to save space.

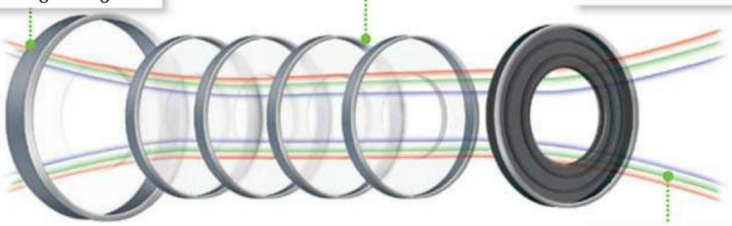
microSIM
For those people who buy the 4G version of the iPad they will need a contract with a microSIM which is inserted here.



Dock connector
The iPad, iPhone and iPod all use Apple's proprietary 30-pin connection plug. You need a specific charger to recharge the iPad.

Communication
This tiny chip located on the logic board handles most of the communications on the device. It's a Broadcom BCM4330 802.11a/b/g/n MAC/baseband/radio with integrated Bluetooth 4.0+HS and FM transceiver.

Radiant results
With the light filtered and the sensor working hard images look great.



Five filters
The light is filtered five times before it reaches the sensor.

More light
The more light that gets into a camera the clearer the pictures.

IMPROVED iSIGHT CAMERA

The camera in the new iPad has been upgraded to a five-megapixel sensor and, while this may not seem like a lot, Apple is keen to point out that lens tech is as important as megapixels. In the third-generation iPad Apple utilised the same five-element lens that resides in the iPhone 4S. This works by filtering light five times to ensure that the colours you see on screen are the same as those you see in real life. This is done by cutting out frequencies like infrared and ultraviolet.

BETTER BATTERY

Apple has managed to up the capacity of the new iPad's battery by a whopping 70 per cent. The iPad battery is made of a 42.5-watt-hour rechargeable lithium-ion and delivers an impressive ten hours of web surfing, video watching or listening to music. Lithium is used as it is the lightest metal and its properties allow it to be recharged at any time. Additionally it doesn't suffer from crystal buildup, which can affect other forms of battery. As you can see from the teardown the battery occupies more space than anything else inside the tablet.



iPad 2010

The original iPad set the tablet computing market ablaze when it was released with a form factor and feature set unrivalled at the time.

Display size: 24.6cm (9.7in)
Resolution: 1,024 x 768, 132ppi
OS: iOS 5.1
Processor: 1GHz Apple A4
Memory: 512MB
Battery: 25-watt-hour lithium-polymer battery
Camera: None
Connectivity: Wi-Fi, 3G, Bluetooth
In-built storage: 16GB, 32GB, 64GB
Pricing: £429 ($499)



Defining feature
The whole feature set was a revelation but the iPad's stunning battery life meant it was always on.

Worst feature
The lack of cameras was immediately noticeable and requested en masse.

iPad 2 2011

The iPad 2 was a big leap forward, not only greatly slimming down the original but also hiking up power.

Display size: 24.6cm (9.7in)
Resolution: 1,024 x 768, 132ppi
OS: iOS 6.1.3
Processor: 1GHz dual-core Apple A5
Memory: 512MB
Battery: 25-watt-hour lithium-polymer battery
Camera: 0.7MP
Connectivity: Wi-Fi, 3G, Bluetooth
In-built storage: 16GB, 32GB, 64GB
Pricing: £329 ($399)



Defining feature
The star feature of the iPad 2, compared to its forerunner, was the enhanced, super-speedy processor.

Worst feature
Disappointingly, the cameras used on this model were woeful to say the least.

New iPad 2012

A similar shape but with an improved screen, battery, processor and camera.

Display size: 24.6cm (9.7in)
Resolution: 2,048 x 1,536, 264ppi
OS: iOS 6.1.3
Processor: A5X dual-core processor with quad-core graphics
Memory: 1GB
Battery: 42.5-watt-hour lithium-polymer battery
Camera: 5MP
Connectivity: Wi-Fi, 3G, 4G LTE, Bluetooth 4
In-built storage: 16GB, 32GB, 64GB
Pricing: From £399 ($499)



Defining feature
Without a doubt the feature that makes this version stand out is the pixel-packed Retina display.

Worst feature
Although the rear camera is better, the front-facing camera is still pretty poor.

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"Any repetitive sounds used in the track are recognised and reused, to save space"



How MP3 players work

How can such a small device store entire music libraries in your pocket?

MP3 is a digital encoding format that uses a special data compression algorithm to greatly reduce the size of audio data files. The format identifies four areas of sound that are not necessary to the playback of a track – from the original recording by the artist – and removes them from the file, reducing the amount of data and allowing more tracks to be saved per hard disc.

There are four different ways that recorded music is compressed into MP3 format. First, the very high tones – those over 20,000Hz, which cannot actually be discerned by a human ear – are not stored. Second, quiet sounds at one pitch that are being blocked out by louder sounds at another are not recorded. Third, any repetitive sounds used in the track are recognised and re-used, allowing for one sound byte to replicate many and thereby save space. Finally, very low tones of under 20Hz – which again cannot be heard by humans – are not recorded.

These techniques, together with only recording left and right audio channels when absolutely necessary, allow a traditional CD-quality audio track to be reduced in size by roughly 11 times.

How silencers muffle sound

How do these special modifiers suppress the bang of a gunshot?

Gun silencers suppress the noise that a weapon makes by slowing the release of expelled gases generated by a cartridge post-shot, a process that involves reducing gas pressure.

This is achieved with a series of sound-restraining baffles within the suppressor's long, cylindrical casing, which is fitted to the end of the gun barrel. The baffles are located down the barrel's interior and are angled at 90 degrees to one another at even intervals.

Behind the baffles, at the base of the silencer's casing, is an expansion zone; this allows expelled gases to increase in volume before coming into contact with the baffles. Over the length of the cylinder, this diverts and slows the gases emerging behind the fired round. Typically, applying a silencer to a weapon will drastically reduce the gas's pressure from around 211 kilograms-force per square centimetre (3,000 pounds per square inch) to below seven kilograms-force per square centimetre (100 pounds per square inch). Of course, the centre of the suppressor's cylinder is kept clear to allow the bullet to pass through without obstacle.



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5 TOP FACTS TATTOO GUNS

Stencil
1 The first tattoo gun was an evolution of Thomas Alva Edison's Stencil-Pen, which was patented in Newark, USA, in 1876. The pen was originally conceived to replicate images.

Face
2 Due to rapid improvements in the precision of tattoo guns, a new form of facial tattooing has emerged in the last decade called dermapigmentation, a kind of permanent cosmetics.

Misnomer
3 Interestingly, many professional tattoo artists look down on the term 'tattoo gun'. Most who work in the industry prefer to use the terms 'tattoo machine' or 'tattoo iron'.

Control
4 Modern tattoo guns offer super-refined control over their operation, allowing the artist to select the depth, force and speed of the needles' application to the skin.

London
5 The first proper tattoo gun was patented in London by engineer Samuel O'Reilly in 1891. The first coil-based tattoo gun was also patented in London.

DID YOU KNOW? *The Swiss Army knife originated in Switzerland in 1897*

Next-generation multi-tools

When a knife and a tin opener simply aren't enough...

Modern multi-tools have augmented the base design with a variety of advanced features, including USB storage memory, laser pointers, pressurised ballpoint pens, flashlights and diamond-coated files. The modern multi-tool's features demonstrate how the average tool has evolved since its conception in the late-19th Century. A Class-II laser pointer with a 3.3-millimetre (0.13-inch) laser diode is fitted in the tip of the multi-tool, connected via gold-plated contacts and a solid brass optical housing to the body. The laser works as it is controlled by an Advanced Power Control (APC) microprocessor, which maintains power output continuously when active to ensure a strong beam with a range of 100 metres (328 feet).

Tools can also be fitted out with a USB drive. This works by occupying a cavity and rotating out on a pivot when needed, or it can be completely detached from the body via a plastic clip at the base. The drive remains small enough to be enclosed due to its 128 gigabytes of flash memory. This is a common feature on newer tools, as solid-state memory allows good data read and write speeds. In some examples, it's possible to get 30 megabytes per second, 23 megabytes per second respectively. Data transfer and management is handled by a mass storage class controller.

Micro ballpoint pens can be mounted to the tip of the multi-tool and can be withdrawn when not in use. The pens are fully pressurised with an airtight seal, allowing it to remain compact but also write in multiple orientations and conditions. Blades are sharpened to a 15° angle and checked during construction with a laser-reflecting goniometer. This allows modern tools to have shorter and more compact blades, but with greater sharpness consistency and damage threshold.



Laser
A red, visible, Class-II laser with a range of up to 100 metres (328 foot), the multi-tool's pointer is ideal for presentations.

Pen
Forgot your pen? Not a problem, as the multi-tool is fitted with a fully pressurised ballpoint at the tip.

Scissors
A staple of multi-tools worldwide, a small pair of collapsible scissors is included for trimming nails or paper.

USB
Multi-tools come with a variety of storage versions ranging from 2GB up to 128GB, data storage is easy and without compromise.

Blades
Modern tools still come with a selection of blades for cutting, filing or opening stubborn cans of foodstuffs.

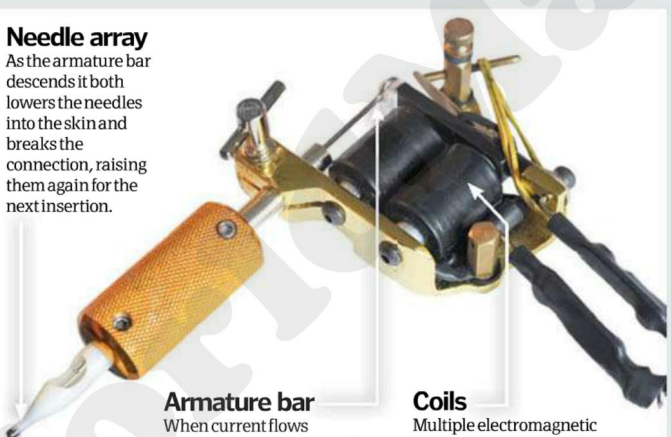
How do tattoo guns work?

The invention designed to transform the skin into a living canvas

Tattoo guns, also commonly known as tattoo irons or machines, come in a variety of forms. The most common variant, however, is the coil type, which utilises a series of electromagnetic coils to raise and lower needles into the skin to deposit the ink. These devices work by connecting an armature bar via a spring to a base unit, which itself contains between one and three electromagnetic coils. The coils connect to a DC power supply via a sprung U-cable and, when powered, act as an electromagnet, pulling down the armature bar.

Attached to the armature bar is the machine's needle array, and as it descends so too do the needles, piercing the skin and depositing ink just below the surface. At the bottom of the bar's descent its connection with the electromagnet breaks and, as a result, it lifts back to the default position. As such, the needles are constantly drawn up and down at a high speed in a cycle.


An international tattoo convention is held each year in London



Needle array
As the armature bar descends it both lowers the needles into the skin and breaks the connection, raising them again for the next insertion.

Armature bar
When current flows through the coils, they pull down the armature bar.

Coils
Multiple electromagnetic coils are powered by a direct current energy supply.

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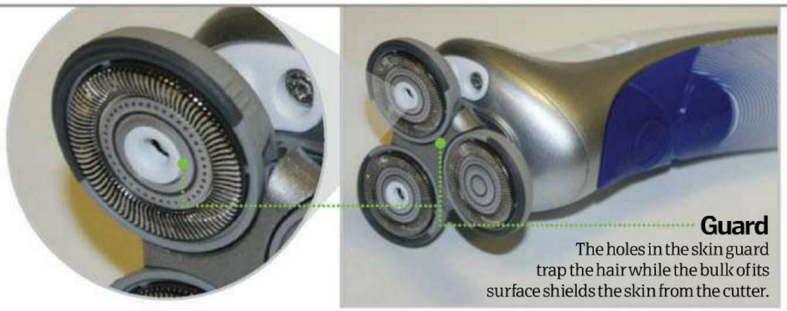
"In a rotary-headed shaver there are multiple foils – often three"

How electric shavers work

Shaving was once a contact sport, until electric shavers took the danger out of trimming your beard

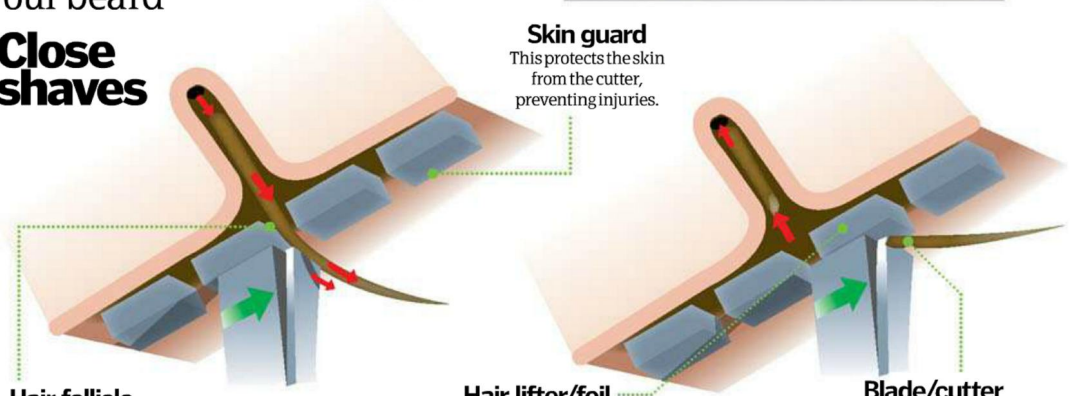
There are two vital components to a shaver: the foil and the cutter. The foil lifts and traps the hair in place for the blade to cut it. Straight foil razors have very thin foils peppered with a network of holes through which the hair is pushed as the shaver moves over the skin. The cutter, positioned behind the foil, then cuts the hair. This sort of shaver can safely be pressed against the skin to make sure the shave is as close as possible.

In a rotary-headed shaver there are multiple foils – often three – over three separate circular blades. The foils are suspended on springs, meaning that they conform to the shape of your face when you use them, ensuring a closer shave.



Guard
The holes in the skin guard trap the hair while the bulk of its surface shields the skin from the cutter.

Close shaves



Skin guard
This protects the skin from the cutter, preventing injuries.

Hair follicle
The action of the foil trapping the follicle raises it slightly, allowing for a closer shave.

Hair lifter/foil
This elevates the hair, simultaneously trapping it in place and enabling it to be cut.

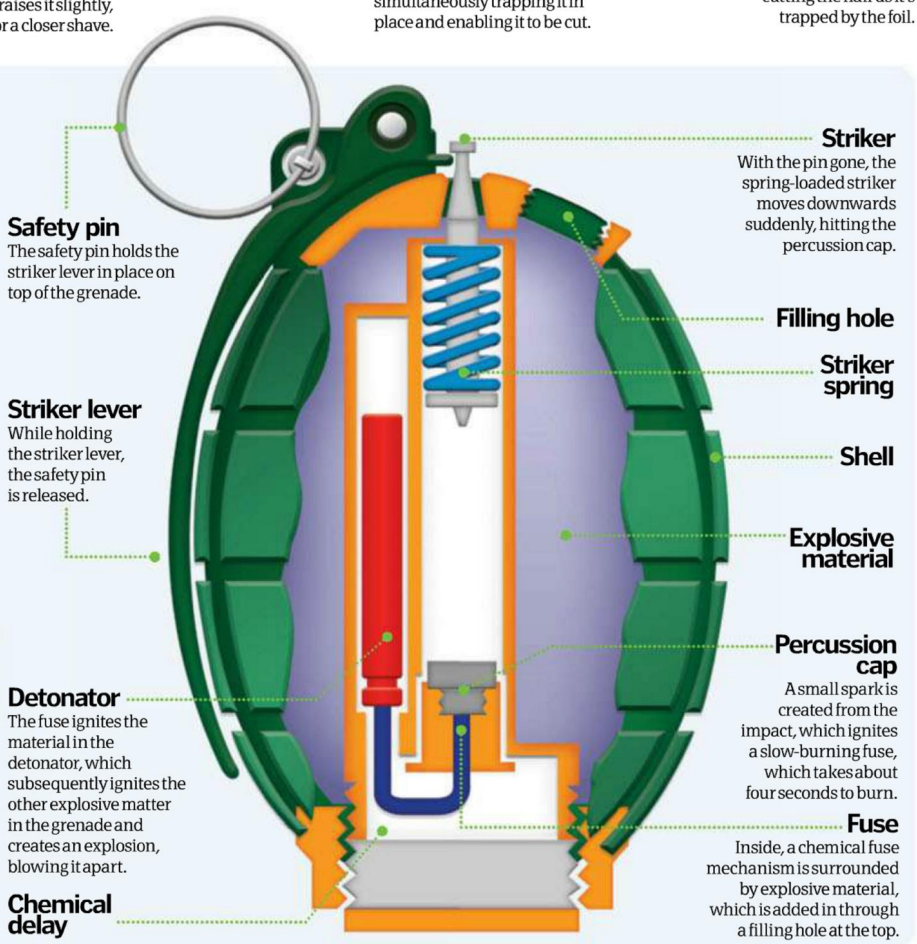
Blade/cutter
The cutter rotates in place, cutting the hair as it's trapped by the foil.

Hand grenades

How do these timed explosives work?

Grenades have been around for over a thousand years since the development of gunpowder allowed for these portable explosives to be made. Modern designs are influenced by these early, primitive explosives, but they are now much safer for the user and more practical. While there are several types of grenade, the time-delay grenade is most commonly used on the battlefield. These grenades are designed to fire out dozens of metal fragments in all directions. Have a look at our diagram to see just how they work.





Safety pin
The safety pin holds the striker lever in place on top of the grenade.

Striker
With the pin gone, the spring-loaded striker moves downwards suddenly, hitting the percussion cap.

Filling hole

Striker spring

Striker lever
While holding the striker lever, the safety pin is released.

Shell

Explosive material

Percussion cap
A small spark is created from the impact, which ignites a slow-burning fuse, which takes about four seconds to burn.

Detonator
The fuse ignites the material in the detonator, which subsequently ignites the other explosive matter in the grenade and creates an explosion, blowing it apart.

Fuse
Inside, a chemical fuse mechanism is surrounded by explosive material, which is added in through a filling hole at the top.

Chemical delay

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5 TOP FACTS
EXPERT FLASH TIPS

Change direction
1 If possible, aim the head of the flash up to the ceiling and bounce the light back down onto your subject. This will help to create a much more flattering light.

Soften and disperse
2 Use a diffuser such as tracing paper over the flash head or a specialist Sto-Fen to soften the intensity of the flash and disperse light more evenly around the frame.

Filling in
3 Turn on your camera's flash when the light behind your subject is strong; this will bring them out in the foreground of the frame by filling in with flash.

Avoid bounce
4 When using flash, ensure there is nothing positioned in front of your subject as this will catch the light first and create a bright distraction in your image.

Know when to use the flash
5 Stationary subjects don't always require flash lighting. The only time you need to use it is when you need to fill in or capture fast-moving subjects.

DID YOU KNOW? *In the late-19th century magnesium flash powder became popular despite the risk of lethal explosions*

How an on-camera flash works

Find out how a six-volt camera generates enough power to fire a flash of 5,000 volts

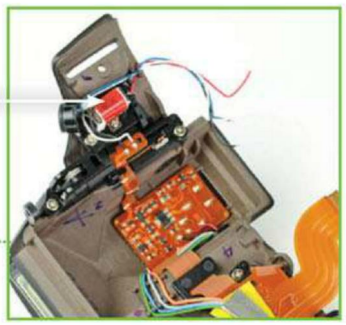
A flash can create a sudden burst of light in just a fraction of a second. Here you'll discover how an on-camera flash really works and explore the scientific process behind it.

All cameras come with a built-in flash designed to help illuminate a scene when shooting in low light. Varying in type, size and strength, when used correctly a camera flash can enhance your photographs. Flash is ideal for filling in shadows with light, and is also used to freeze motion, ensuring sharper shot results.

Once a compact camera has been switched on it will automatically begin charging the flash capacitor. Used like a battery, the capacitor is capable of storing around 300 volts – just enough to help fire the camera's flash when low light is detected. As a camera's battery is only capable of providing six volts, a transformer is used to convert this directly for storage into a higher voltage of around 300.

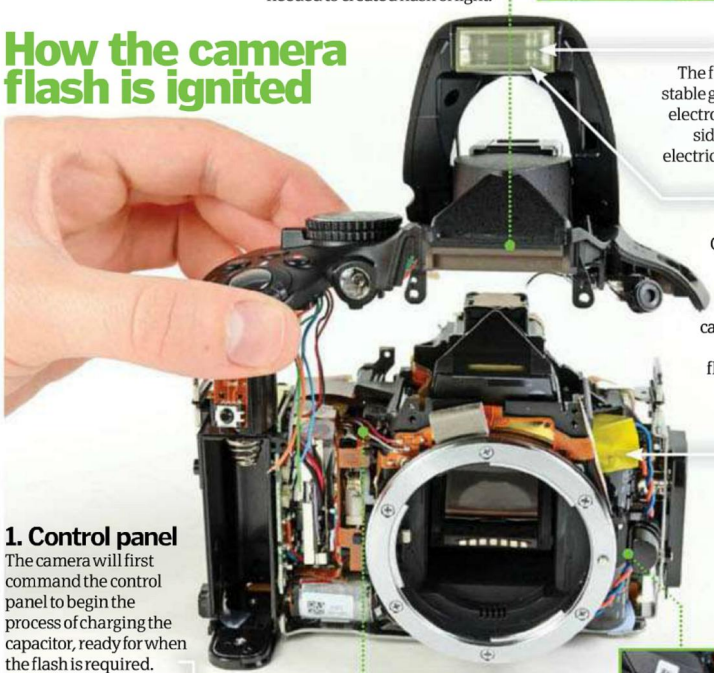
When taking a photograph, the camera determines if there is enough light to correctly expose the image and, depending on your flash settings, will automatically trigger the flash. As the shutter release button is being pressed, some of the 300 volts stored in the capacitor will then run through a trigger coil transformer, converting them further from 300 to 5,000 volts. This high voltage is then conducted by two electrodes, positioned either side of a flashtube, which emits the flash of light. This flashtube is filled with a stable, or noble, gas called xenon. The current emitted by the electrodes excites the xenon atoms, freeing electrons and ionising the gas.

Now the gas is conductive, electrons that remain in the capacitor are released. The flash is generated as the gas atoms in the flashtube collide with the electrons. This flash of light is as bright as over 2,000 lightbulbs in just a fraction of a second, just enough time to capture that shot.



4. Trigger coil transformer
When ready to shoot, the trigger coil transformer converts the stored 300V into 5,000V – the amount needed to create a flash of light.

How the camera flash is ignited

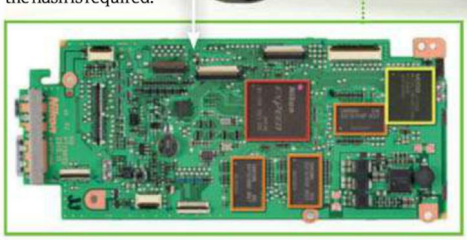


5. Flashtube
The flashtube contains the stable gas xenon and has two electrodes positioned either side designed to conduct electricity and ionise the gas.

6. Creating light
Once ionised, xenon is highly conductive; further electrons are released from the capacitor colliding with gas atoms in the flashtube and creating a bright flash of light.

2. Transforming voltage
To generate enough power to fire the flash, a transformer (not visible) will convert the camera's low 6V into 300V.

1. Control panel
The camera will first command the control panel to begin the process of charging the capacitor, ready for when the flash is required.





3. Storing volts
The capacitor then stores the initial 300V needed to help ignite the flash.

4x © iFixit.com

Flash results



NO FLASH
There is a warm orange cast as the model has only been lit by the tungsten room lighting. There is also camera shake present due to slight movements; this could have been avoided had we used the flash.



FLASH ON
The image was taken with a direct on-camera flash. The bright harsh light flattens the image and creates strong contrast and shadows. Not flattering to light an entire scene, on-camera flash is best used to fill in light on bright days.



BOUNCED FLASH
This image was taken using an external flash light (speedlight); the flash head was rotated and the light was bounced off a white ceiling. This technique creates a softer, more flattering light for portraiture.

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"Phase detection is the most common AF system due to its speed and focus accuracy"

Camera autofocus



© Samsung

Autofocus is an important component in photography so let's take a closer look at how it really works

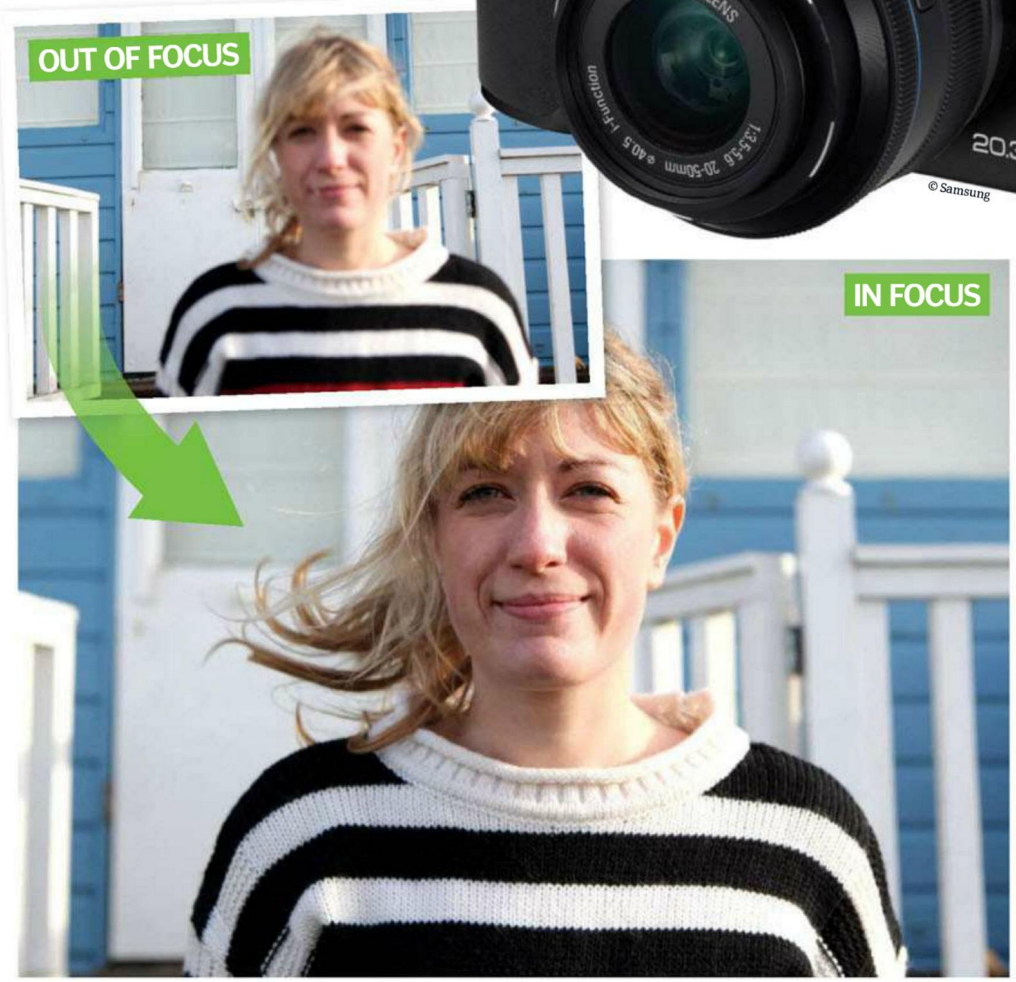
Autofocus (or AF) is one of the key elements in a camera and can determine how successful your final photographs are. Many rely solely on the camera's autofocus setting when shooting as it can be a guaranteed way to ensure your shots are sharp.

There are two types of autofocus: active, which is commonly used in point-and-shoot compacts, and passive, which features more in high-end camera models. Arguably passive is the quickest and more reliable of the two and has two specific focus systems: phase detection and contrast detection.

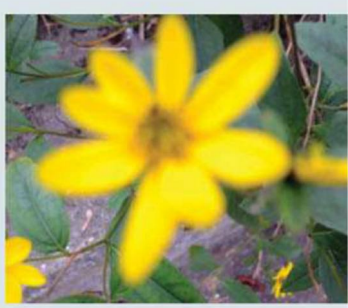
Phase detection is the most common due to its speed and focus accuracy. Once you have composed your image in-camera you will need to depress the shutter button halfway so the camera can find a focal area to lock on to. While this is happening, the image you intend to shoot will enter the lens and get split into two. Depending on the distance between your subject and camera lens these images should run evenly alongside each other before being separated through two microlenses and then projected individually onto two small AF sensors. The images should each meet the AF sensors directly for the image to be in focus and should not overlap or be too far from each other – in other words, out of phase. By comparing the projected images on the two sensors, the camera's built-in AF unit will then ascertain whether the shot is front focused, back focused or fine as it is.

Depending on the results, the AF unit can determine how far and in what direction the lens needs to be moved in order to phase and accurately focus the photograph. Directing a small motor that is powered by the camera's battery, the lens will then be repositioned at the right distance from your subject to ensure you get the optimum blur-free results.

It may seem like a long process but all this in fact takes only a fraction of a second and is one of the most sure-fire ways to get great snaps.



Focus locking



The majority of cameras – particularly compacts – have only one central focus area; this means your final image's focus area will fall within the centre of the frame and often in the background of a large scene. If, however, you want to focus on a subject in the foreground, which may be slightly off-centre, you will need to override the camera's automatic instincts.

Begin by repositioning your camera so the foreground subject is in the centre of the frame. You can now focus the camera by pressing the shutter-release button down halfway. Holding your finger in place will lock the camera's focus, allowing you to position the camera back to the original composition ready to shoot.

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5 TOP FACTS
AUTOFOCUS ADVICE

Autofocus settings
1 Most cameras offer both single AF and continuous AF shooting modes. Use continuous AF when you're photographing fast-moving subjects as it helps to keep action shots sharp.

Eyes on the prize
2 When shooting portraiture or even wildlife, it's a good idea to focus the camera on your subject's eyes as this is where the viewer will naturally be drawn to.

Rule of thirds
3 When shooting a landscape, always try to focus the camera one-third of the way into the frame; this will help to ensure that as much of the image is in focus as possible.

Macro mode
4 Don't forget to use your Macro mode when capturing closeups. This will enable you to shoot at a closer distance to your subject, filling the frame with much more detail.

Set a focus point
5 Most cameras offer focus point settings that enable you to adjust where in the image the camera should home in on. Explore your camera's menu settings to find out what options are available.

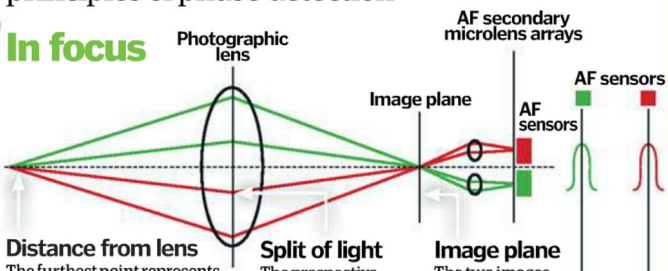
DID YOU KNOW? *Polaroid cameras first used SONAR technology to determine the correct AF distance required*

Phase-detection autofocus in action

Take a closer look at the main principles of phase detection



In focus

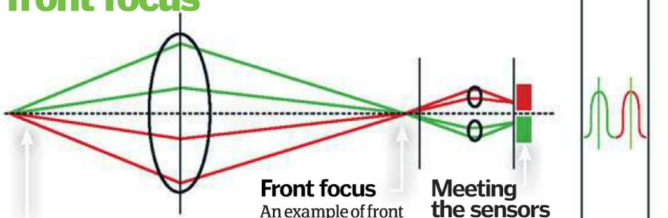


Distance from lens
The furthest point represents how far the subject is from the camera lens.

Split of light
The prospective image will be split in two when it enters the camera lens to determine the focus accuracy.

Image plane
The two images should converge evenly at the image plane before projecting onto the AF sensors.

Inaccurate front focus

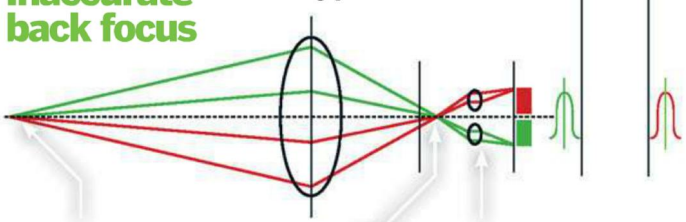


Distance from lens
The subject is closer to the lens so is more likely to be out of focus due to the short distance.

Front focus
An example of front focus as the two images have converged too soon so they overlap before reaching the image plane.

Meeting the sensors
The split images are too close together to meet the AF sensors accurately.

Inaccurate back focus



Distance from lens
The subject is at a notably further distance from the camera lens here.

Back focus
Due to the distance between the subject and lens the images converge too late to pass through the microlenses accurately enough.

Microlenses
Once the split images meet at the right point, they should pass through the microlenses to be directed onto the AF sensors, but the images are not aligned here resulting in blurriness.

Active versus passive

There are two different types of autofocus: active and passive. Most point-and-shoot compacts use an active system whereas pro DSLR cameras rely on faster and more accurate passive AF. What really sets them apart is how they measure the distance between the subject and camera in order to set the correct focus.

Active AF systems determine distance using infrared light that reflects off the subject back into the lens. The camera's AF system will then work out how long in time it takes to receive the bounced light back before calculating where the lens needs to move to focus the frame. This is rarely instant and you are limited to shooting at shorter distances.

Passive autofocus systems, on the other hand, determine distance by analysing the proposed image first without using infrared rays. Using either phase-detection or contrast-detection techniques, the camera relies on small AF sensors to establish where the lens needs to be placed in order to focus your shot.

Where the phase-detection system sits inside the camera

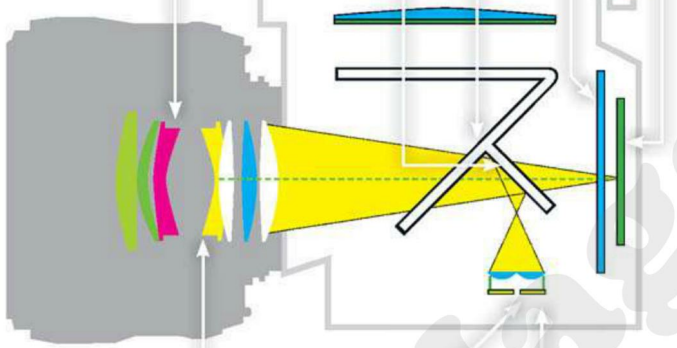
Sub-mirror
This smaller mirror reflects the two split images down through the microlenses.

Main mirror
This mirror flips up when the shutter is pressed.

Image sensor

Camera lens
The prospective image enters the camera lens and is divided into two.

Shutter



Lens-driving controller
Receiving the information from the AF unit, the lens-driving controller will then instruct a motor to reposition the camera lens as required.

Small AF sensors
The two AF sensors receive the split images individually and determine how in focus the final image will be based on their alignment.

AF unit
The camera's autofocus unit then calculates how far the lens will need to be adjusted in order to correct an out-of-focus photo.

Step 1
The camera will automatically focus in on the centre of the frame and usually on the largest area, which in this image is the background.





Step 2
To bring the flower into focus the shot is re-composed, placing the bloom in the centre. The shutter is pressed halfway to focus on the flower and held.



Step 3
Still holding down the focus, the camera is moved back into its original position and the shot is taken. The flower is now perfectly in focus.

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"They were originally designed for making POV surfing videos but now cover a range of extreme sports"

How action cameras record on the go

What makes a cutting-edge wearable camera tick? We probe inside the GoPro HERO3...



HERO3 exploded

We take a peek inside GoPro's latest mountable action-cam

Backing
The waterproof cover for the battery compartment.

Speaker
The speaker and the button assembly are attached to the back.

Housing
The innards are kept in toughened plastic that is waterproof to 60m (180ft).

Battery
This 1,050mAh lithium-ion rechargeable cell has a pull-tab for easy release.









GoPro has been making wearable cameras for nearly a decade now, since its debut 35-millimetre (1.4-inch) film camera system was launched in 2004. They were originally designed for making point-of-view surfing videos but have now expanded to cover a huge range of extreme sports and pursuits, including diving, skydiving, motocross and more or less anything where a hands-free video recorder is required.

The principal features of these cameras have always been that they are small and lightweight, shockproof and waterproof, and compatible with a host of mounts that enable them to be securely attached to the user and get up close to the activity. They also use multimedia technology that allows for crisp audio and video capture at speedy frame rates.

There are three versions of the GoPro HERO3, all of which can record 1080p-resolution video at a minimum 30 frames per second, with the top-end Black edition capable of the latest 4K video at 15 frames per second. The standard photo mode can snap 5-12-megapixel shots at regular intervals of 2-60 seconds, although it differs from standard digital cameras in that there is no zoom lens or viewfinder. In any case the GoPro HERO is designed to be activated and left to its own devices, rather than manually operated, enabling the user to focus their full attention on the extreme sport at hand.

Finally, the vital mounting components comprise a comb joint, nut and bolt, and the GoPro HERO3 also boasts mounts tailored especially for handlebars, roll bars (for sports cars), helmets and a chest harness.

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Daughterboard
This has an extra port for a microSD as well as proprietary GoPro accessories like the 3D HERO system.

Image sensor
This Sony-made IMX117 sensor detects up to a 12MP resolution at 35 fps.

A real hero: Felix Baumgartner

Easily the GoPro HERO3's most prominent media use to date was in the Austrian skydiver Felix Baumgartner's record-breaking Red Bull Stratos freefall. On 14 October 2012, Baumgartner took a specially designed helium balloon into Earth's stratosphere, setting an altitude record at just under 39 kilometres (24 miles) for a manned balloon flight (the edge of space, incidentally, is found at 100 kilometres/62 miles). He then jumped out of the balloon and set the world record for the highest parachute jump and, during the same jump, achieved a speed of 1,357.6 kilometres (843 miles) per hour for the greatest human freefall velocity ever achieved.

The entire event was recorded using five GoPro HERO3 cameras, all strapped to various parts of Baumgartner's body and positioned in strategic point-of-view angles. Naturally, they caught the moment he broke the sound barrier – the first person ever to do this in freefall.

Another dimension

GoPro has a number of accessories that enhance a multimedia capture device of this kind in the field, but one of the more sophisticated and interesting systems has to be the 3D HERO.

This is essentially a housing that lets you combine two GoPro cameras together, side by side. Once in place, either end of a cable plugs into the rear port of each of the cameras to synchronise video, photos and sound. As the apertures of each camera are separated by no more than a couple of centimetres (like our eyes), the data captured is very similar but still differs slightly. It's just enough for a bespoke piece of software to stitch the video or still images together to create a three-dimensional result. This can then be viewed with a pair of 3D anaglyph glasses. Because the 3D anaglyph data is the result of two 2D images, both 2D and 3D footage can be recorded simultaneously.

LCD
This simple display is used to show image settings like fps and resolution, rather than display images.

Motherboard
The main camera chipset includes CPU, integrated flash memory (for storage), 512MB RAM, as well as Bluetooth and USB controllers.

Lens
This is the ultra-sharp, aspherical glass lens that lends a fisheye view to both photos and videos.

© iFixit.com; GoPro

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"Camera interiors have also advanced with improved sensor technology, and increasing megapixel counts"

Next-gen camera technology



Discover the latest advancements in photographic hardware and software

Over the last few years, we have seen some huge developments in digital camera technology. With improved designs and features, manufacturers have enhanced the capture process, ensuring that even a beginner can achieve professional-looking shots regardless of whether they're working with a DSLR or compact camera system.

Raising a few eyebrows along the way, there have been some developments that have stirred up debate – notably in 2008 when HD video was first introduced within a DSLR camera. Met with heavy criticism from the offset, it has only been in the last couple of years with improved performance and acceptance that HD video modes are now considered a standard feature. Equally in 2009, the introduction of 3D technology proved fairly controversial although it has yet to be considered groundbreaking.

Headlining changes, however, have seen camera bodies shrink, while others have been combined. In 2008 the introduction of a completely new camera system – the mirrorless interchangeable lens camera – took the consumer market by storm with product sales now competing with entry-level DSLRs.

Camera interiors have also advanced with improved sensor technology and increasing megapixel counts; indeed, image quality is the best it's ever been. Standard shooting modes have also had revivals with enhanced auto modes now capable of great shots, without you having to understand the theory behind photography.

With all of these exciting advancements in camera tech, photography has become accessible to the masses, making it popular with both young and old generations. We look into some of the latest developments and uncover how they are transforming the field of photography.



DID YOU KNOW?

Extreme geotagging

Most cameraphones will automatically geotag your location when you take a shot. This information is then stored in the image data, which isn't always removed if you upload pictures online. Many celebrity home addresses have been discovered this way via social-networking sites such as Twitter.

DID YOU KNOW? *In a normal camera sensor, green is the most abundant photodiode as the eye is more receptive to this colour*

Multiplying megapixels

For a long time, camera manufacturers were at war when it came to their sensor sizes and megapixel counts. Over the last few years, however, a lot more focus has been placed on improving the image quality, refining the sensors and developing new technology.

Camera maker Sigma has made considerable inroads into this territory having used some of the latest sensor technology in its new flagship DSLR model, the SD1. Featuring a Foveon X3 direct image sensor, the SD1 offers a staggering 46 effective megapixels, a significant amount for a camera of its type. It is only through comparison with a conventional image sensor that it becomes apparent just how the Foveon X3 packs such a powerful megapixel punch.

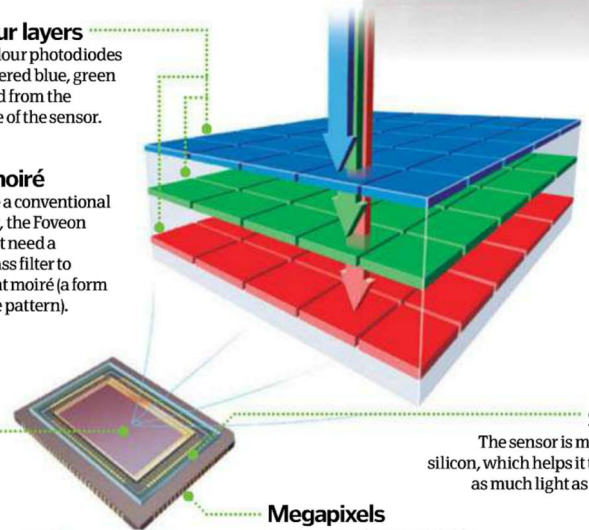
Essentially, all image sensors are monochrome and can only detect the intensity of light as opposed to the colour. It is an additional layer of photodiodes that filter the light through to the sensor that make it receptive to colour rays. In a standard colour filter sensor, each pixel is made responsive to one select primary colour of red, green or blue (RGB). The photodiodes are patterned to cover each pixel and are laid out in rows, which alternate between red and green in one row and blue and green in another. As each pixel records only one colour ray of light, a process known as colour interpolation is used to ensure that the final colour image is accurate. What the Foveon sensor does differently is ensure that every pixel can receive and capture full RGB colour using a layering system of photodiodes.

This setup therefore enables the image resolution to be multiplied by three, as effectively each pixel within the Foveon sensor encompasses three pixels to a conventional image sensor's one.



5x © Sigma

Foveon X3 sensor vs a conventional colour filter sensor



Colour layers
The colour photodiodes are layered blue, green and red from the surface of the sensor.

No moiré
Unlike a conventional sensor, the Foveon doesn't need a low-pass filter to prevent moiré (a form of false pattern).

Silicon
The sensor is made from silicon, which helps it to absorb as much light as possible.

Megapixels
23.5 x 15.7mm (0.93 x 0.62in) in size, the APS-C X3 image sensor offers 46 effective megapixels.

Mosaic capture

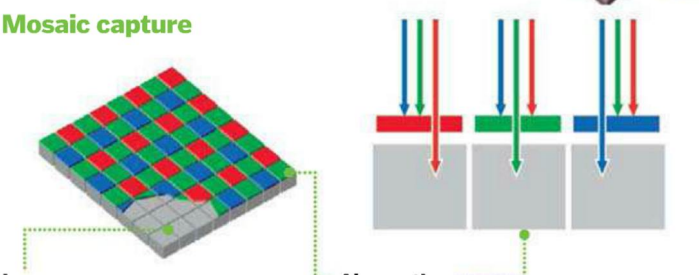
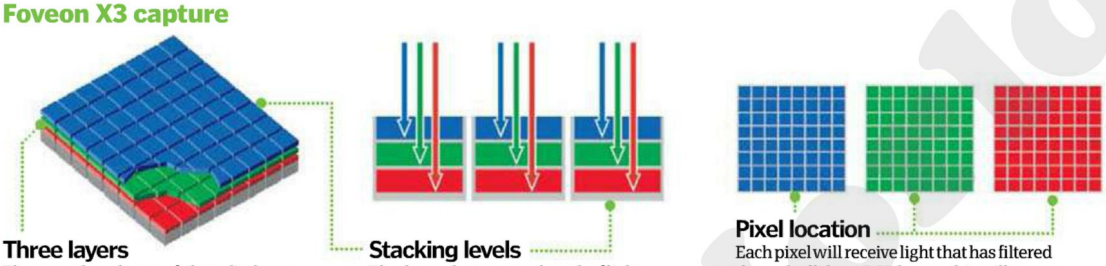


Image sensor
The sensor is monochrome and will only detect the intensity of light as opposed to the colour.

Absorption
Due to the pattern and the frequency of green, only 25 per cent of red and 25 per cent of blue light is recorded compared to 50 per cent of green.

Mosaic of colour
The grid of photodiodes is laid out in rows with green/red then green/blue. Each pixel is then responsive to one colour.

Foveon X3 capture



Three layers
There are three layers of photodiodes on the Foveon X3 that represent each of the primary RGB colours.

Stacking levels
Blue has a shorter wavelength of light so it appears closer to the surface of the sensor than red or green.

Pixel location
Each pixel will receive light that has filtered through all three RGB layers; this will ensure accurate colour reproduction and increase the image size and megapixel number.

Geotagging around the globe

Geotagging is a developing form of technology that has eagerly been introduced into outdoor consumer cameras. Enabling photographers to mark where exactly in the world a photograph was taken, geotagging requires a camera to feature a GPS chip. This GPS receiver can then communicate with a network of orbiting satellites around the Earth to pinpoint the photographer's exact position, using the principle of triangulation. The longitude and latitude co-ordinates are then stored as part of the image's metadata, which you can opt to share online when uploading images to social networks etc.



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© Pentax

Tough camera builds

Camera bodies have toughened up considerably thanks to improved build designs and materials. With recent advancements, we've seen cameras emerge that are capable of withstanding almost all of the elements. Offering shockproof, waterproof and freezeproof resistance, manufacturers have ensured you can continue shooting whatever the weather.

Pentax, for example, recently announced its latest outdoor compacts: the WG2 and WG2-GPS. Resembling a transformer, this 16-megapixel compact is capable of shooting underwater down to depths of 12 metres (39 feet), is shockproof from 1.5 metres (4.9 feet) and can withstand freezing conditions up to -10 degrees Celsius (14 degrees Fahrenheit).

Made from a shock-resistant polymer and elastic material, the WG2's unique outer shell is built like protective armour. With angular ridges and corners, its distinct design offers extra grip when shooting handheld and also goes some way to shelter the lens and back screen if dropped. The interior components of the camera are also protected to some degree from falls thanks to an added special shock-resistant cushioning.

Other elements of the outdoors are kept at bay by rubber-sealed buttons on the body and a specialist locking system on the camera's battery and interface covers. The flash and lens, meanwhile, feature protective glass, which has been glued with extra-strong adhesive to ensure the WG2 remains totally watertight even under pressure.

Merging photos and video

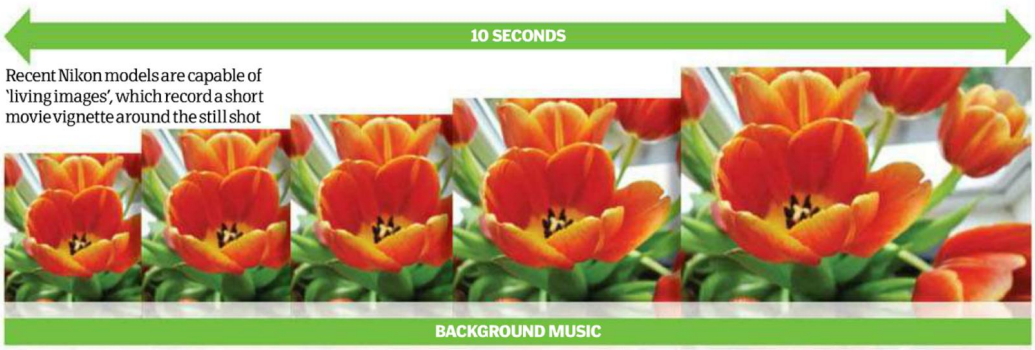


© Nikon

Nikon recently announced the release of its first compact system cameras: the Nikon 1 J1 and V1, both of which incorporate some new and exciting shooting modes.

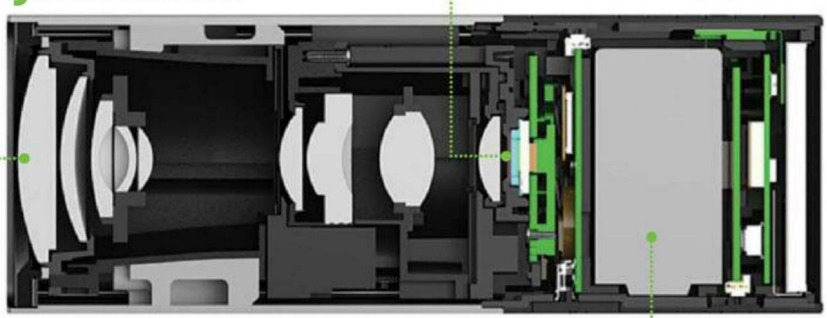
The Motion Snapshot mode appears in both cameras and creates what Nikon describes as a 'living image'. Combining a slow-motion movie file with a still image, this shoot setting enables you to put your photos and video clips together in context. Designed not to slow down the capturing process, the camera will harness its pre- and post-capture technology to record a one-second, 1080p full-HD BGM file while shooting your still. Recording at 60 frames per second, as soon as your finger touches the shutter button, the movie will start capture almost 0.6 seconds before the shutter is fully pressed and continues on for an extra 0.4 seconds once the full-resolution image has been taken. The camera will then process the movie file and slow it down to around 24 frames per second, creating a 2.5-second, slow-motion video clip. Combining both elements together, in playback the camera will sequence the movie footage first before fading into the still. It's an ideal way to share special moments with friends and family online.

Nikon has also developed what's known as the Smart Photo Selector mode. Designed to help ensure you never miss a moment or a great shot, this setting works again with the camera's pre- and post-capture technology. Once this shooting mode has been selected, the Nikon 1 camera will begin photographing 20 full-resolution images at a rate of 30 frames per second, both before and after the shutter button has been released. The camera will then assess each image using a programmed set of good and bad criteria. Factors such as camera blur, composition, smiles, sharpness and blinking will all be taken into account before the camera intelligently selects five final shots for you to choose from including a recommended best.



Recent Nikon models are capable of 'living images', which record a short movie vignette around the still shot

A closer look at the Lytro camera

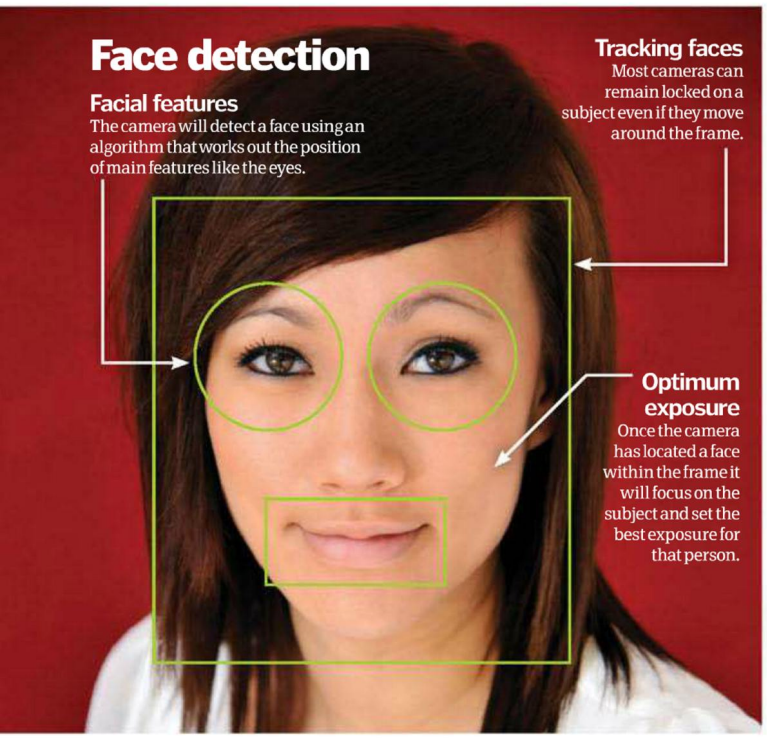


Light-field sensor
The Lytro's light-field sensor captures 11 million light rays, which are measured as megarays rather than megapixels.

Light and lens
Featuring a fixed f2 aperture and 8x optical zoom lens, users can shoot in most lighting conditions.

Light-field engine
The featured light-field engine 1.0 processes the directional light information from the sensor so that you can adjust the image focus at a later stage using specialist software.

DID YOU KNOW? A more advanced version of face-recall tech has been used to help locate criminals in crowds





"Face detection can now also incorporate smile and blink detection, ensuring you get perfect results every time you shoot"

Face detection and recognition

Face detection isn't entirely new technology but recent developments mean its capabilities are greatly advancing. Enabling a camera to automatically locate a face within the frame, face detection works by using an algorithm that detects and triangulates facial features – usually the eyes and mouth. Once a face has been found, the camera will then optimise its exposure and focus for the subject. Even if the person were to move, provided the facial features remain partially in view, the camera would remain locked and track them. Most cameras provide a multiple setting too so that you can do this for more than one person in a frame, to incorporate group shots of up to ten people.

Face detection can now also incorporate smile and blink detection, ensuring you get perfect results every time you shoot. Programmed into the camera, smile detection simply waits for a change in face shape that resembles a smile before the shutter is released to shoot. Blink detection, on the other hand, will quickly review the results of the last image taken to ascertain whether or not a subject has blinked; the camera will then independently decide whether or not to take another shot.

A more recent advancement to face-detection tech is face recognition. A new feature in many cameras – including Pentax's latest Optio VS20 – face recognition enables you to shoot a portrait and then store that face in the camera's memory. Particularly useful if shooting in a crowd, the camera will automatically locate this person to set the best exposure. It's also been used by authorities to track down criminals and terrorist suspects.

Light-field camera technology

Trailblazing ahead with new camera technology, Lytro announced its first product last year: a light-field camera. Incorporating brand-new tech, the Lytro camera enables you to shoot first and then focus your shots later using your computer.

Unconventional in design and build, the Lytro camera is unique in the way that it captures light. Traditionally a camera will find a focal area depending on how far the subject is in relation to the sensor. The Lytro camera, in contrast, records light at various distances from all different directions so that you can opt to select a focal point later, anywhere in the frame.

Built to incorporate light-field technology, the camera features a set of microlenses in front of its image sensor. The light, which then enters through the front lens, is split through the microlenses and is encouraged to fall across multiple pixel locations at different angles. All of this directional data is then recorded in the camera's light-field engine, which will convey the information to the software on your computer when the images are uploaded for focus adjustment.

Available in an 8GB or 16GB model, this revolutionary point-and-shoot camera means that shots can be recycled again and again, simply by changing the focus.



Display
The Fire boasts a seven-inch, multitouch, Gorilla glass display. It is a capacitive touchscreen sporting a 1,024 x 600px resolution.

Processor
A powerful dual-core TI OMAP 4 processor is installed to cope with the high workload. Graphics are handled by a PowerVR GPU.

Storage
The Fire will ship with 8GB of internal drive space for the storage of media like music and books. There's no microSD slot for additional memory.

Power
The Fire has a battery life of eight hours of continuous reading, or seven and a half hours of video playback when Wi-Fi is turned off.

Support
The Fire supports Kindle Format 8, Kindle MOBI, TXT, PDF, PRC, Audible, DOC, DOCX, JPEG, GIF, PNG, BMP, AAC, MP3, MIDI, OGG, WAV and more.

Software
Users will be able to access the Kindle Store, Amazon App Store and both Amazon Cloud Storage and Amazon Cloud Player services directly. It also has Amazon's new cloud-optimised web browser, Amazon Silk.



The statistics...

Kindle Fire

Cost: $199
Content source: Amazon
App store: Amazon App Store, Android App Store
Screen size: 7 inches
Screen resolution: 1,024 x 600px
Size: 190 x 120 x 11.4mm (7.5 x 4.7 x 0.45 inches)
Weight: 414g (14.6oz)
OS: Android 2.3
Storage: 8GB
Processor: Dual-core TI OMAP 4
Battery life: 8 hours

Amazon Kindle Fire

Since 2006 eReaders have grown in both capability and mass-market appeal, with each new device bringing with it a cavalcade of hype. Each invariably claims that it will usher in the era of digital books, or abolish the written word that has played such a constructive and creative role in shaping society, crafting ideologies and enlightening individuals since the invention of the printing press in the mid-15th century. Of course, the dream of digital content is a noble one, with the internet breaking down the traditional barriers of availability, accessibility, storage space and, in some cases, cost. Some of the greatest works of fiction are, after all, now available for free thanks to the burgeoning digital transition, granting millions more individuals across the world access to what before would have been restricted by the aforementioned boundaries. However, until now, these devices only delivered one facet of the written word: the book – their delivery was literally and metaphorically polarised in black and white.

Fast-forward five years and times are changing. Thanks to the emergence of new technologies and infrastructures, eReaders are evolving into a new hybrid

5 TOP FACTS KINDLE FIRE

Silky
1 The Fire is installed with Amazon Silk, a new web-browsing system that speeds up webpage delivery times. Silk caches common web files to its EC2 cloud system in order to transfer them faster.

Lightweight
2 The Kindle Fire weighs just 414g (14.6oz), significantly less than the 601g (21.2oz) iPad 2. The Fire therefore weighs less than a medium-sized bottle of ketchup.

App-tacular
3 As the Fire is based on the tablet variant of the Android OS, it can access both the Android and Amazon app stores. This means users can purchase over 16,000 apps.

Altruistic
4 According to analyst IHS ISuppli, Amazon is making a $10 loss on every Kindle Fire it sells. This is because the device's internal components have been priced up at $209.

Prime
5 The Kindle Fire and Fire HD comes with a 30-day free trial of Amazon Prime, a service that allows free and expedited shipping on millions of items for its members.

DID YOU KNOW? *Unlike the standard Kindle, the Kindle Fire can store and play films and music*

Kindle Fire

Amazon's hot new tablet/eReader hybrid explored

The Kindle Fire is a new device from Amazon that is uniting the role of a tablet with that of an eReader, such as the Sony Reader Touch. Cheap – less than half the price of Apple's iPad 2 and $50 cheaper than the Barnes & Noble NOOK Tablet, versatile – with full tablet functionality, and deeply integrated with a plethora of cloud computing services, it is perceived as a new standard bearer for mass-market digital consumption devices.

The Fire is, in terms of hardware and software, dense. For a comprehensive breakdown of the device's hardware, see our annotated image (left). While branded under the Kindle eReader nomenclature, it's actually closer to a full-blown tablet computer in terms of processing power and functionality.

The key to why the Kindle Fire is being viewed as a game-changer is its integration of the entire portfolio of Amazon cloud computing services, including: Amazon Web Services, Instant Video, Kindle Books, Amazon MP3 music store and Amazon cloud storage. These services, along with other non-native cloud content delivery systems, allow users to access all elements of multimedia content, be that music, movies, internet radio, eBooks, audiobooks, social networks, games and more, from just one device, where they can be streamed from the cloud or stored locally.

The integration of cloud-based services even extends to its new web browser, Amazon Silk. Here, Silk harnesses the power of Amazon's remote EC2 servers to split the browser's subsystems into two categories, with certain systems running locally on the Fire and others handled server side. This, in partnership with Silk's adoption of Google's SPDY networking protocol, enables webpages to be launched and fully operational far quicker than on a standard browser.



Due to the Kindle Fire's capacitive touchscreen, interactive storybooks and games are supported

© Amazon

Anatomy of a classic eReader

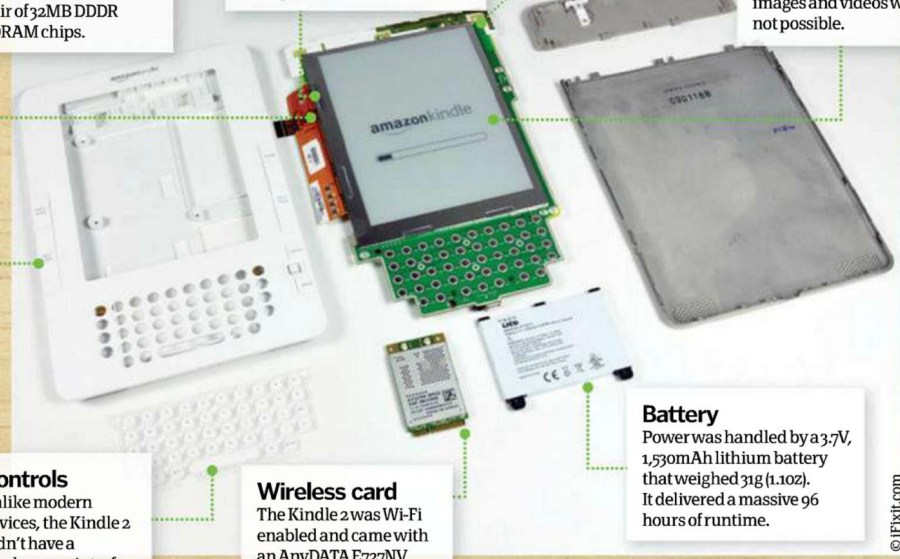
We tear down an Amazon Kindle 2 to emphasise the revolutionary transformation digital reading devices are currently undergoing

Processor
Due to its only prime function being the displaying of eBooks, the Kindle 2 was installed with a Freescale 532MHz, ARM-11 90nm CPU.

Screen
The Amazon Kindle 2 delivered a six-inch, 600 x 800px screen at 167 pixels per inch. It utilised black and white e-ink technology to generate text in 16-level greyscale. Colour images and videos were not possible.

Hard drive
eBooks were stored via 2GB of moviNAND memory. However, only 1.4GB was available for user storage purposes.

Memory
As with the device's low-power CPU, onboard RAM was restricted to a pair of 32MB DDDR SDRAM chips.



Battery
Power was handled by a 3.7V, 1,530mAh lithium battery that weighed 31g (1.1oz). It delivered a massive 96 hours of runtime.

Controls
Unlike modern devices, the Kindle 2 didn't have a touchscreen interface, but physical buttons and a joystick.

Wireless card
The Kindle 2 was Wi-Fi enabled and came with an AnyDATA E727NV wireless networking card for downloading eBooks.

© iFixit.com

Amazon Kindle 2



eBooks can be purchased on the Kindle Fire through the Kindle Store

© Amazon

"The Kindle Fire characterises the shift in concept that the eReader market is currently undergoing"

device, splicing together their traditional role as a portal to consume digital books, with the vast multimedia capabilities offered by tablet computers. Now, thanks to technological advances in physical data storage, LCD displays, electronic ink, CPUs, GPUs and capacitive touch panels, this new breed of digital consumption devices allow their users to read not only the black and white text of their favourite novel, but view its colour images, add bookmarks, notes and commentary to it via touchscreen, share funny or prevalent quotes from it via a social network and access it from a variety of devices directly via the cloud. That's not to mention, of course, that with all that extra power and storage, users can also now take a break from reading all together and access movies, TV shows, music, audiobooks and games without ever having to put down the device.

Key to this evolutionary leap is the development of cloud computing – the delivery of software and information to a local device that is hosted and streamed directly from the internet ▶

"Key to this evolutionary leap is the development of cloud computing"

– which has transformed the ability to deliver digitised content live to consumers. This transition is currently being showcased by the brand-new Kindle Fire from Amazon, a tablet/eReader hybrid that draws together all of the company's extensive cloud-based services into one seven-inch access portal. We will explore this device in more detail later on, but in short it characterises the paradigm shift in concept that the whole eReader market – and in terms of cloud computing, the tablet market as well – is currently undergoing. This is demonstrated in our analysis of the NOOK Tablet from Barnes & Noble too, which is also delivering a host of tablet functions on its popular eReader, having recently updated the platform.

Finally, we turn our attention to the growth of cloud-based services in the digital landscape and the role they play on these tablet devices, as well as explaining exactly how e-ink works.

The physical book may not be dead, but judging by these hot new devices, it sure is getting a run for its money.



© Barnes&Noble

Colour e-ink explained

The next wave of eReaders promises to utilise the revolutionary new technology of e-ink. We take a quick look at how this complex system creates colour images

E-ink (electrophoretic ink) is a form of electronic paper being increasingly used in eReader devices such as the Amazon Kindle, Barnes & Noble NOOK and Sony Reader Touch, as well as in a wealth of other less high-profile products such as wristwatches and advertising billboards.

Now, however, along with the new generation of eReader/tablet hybrids that is emerging, e-ink is itself evolving. Colour displays are now being manufactured that allow the full benefits of an electronic paper display – low power consumption, realistic paper appearance and zero glare to name a few – but with the technicolour capabilities of modern LCD screens.

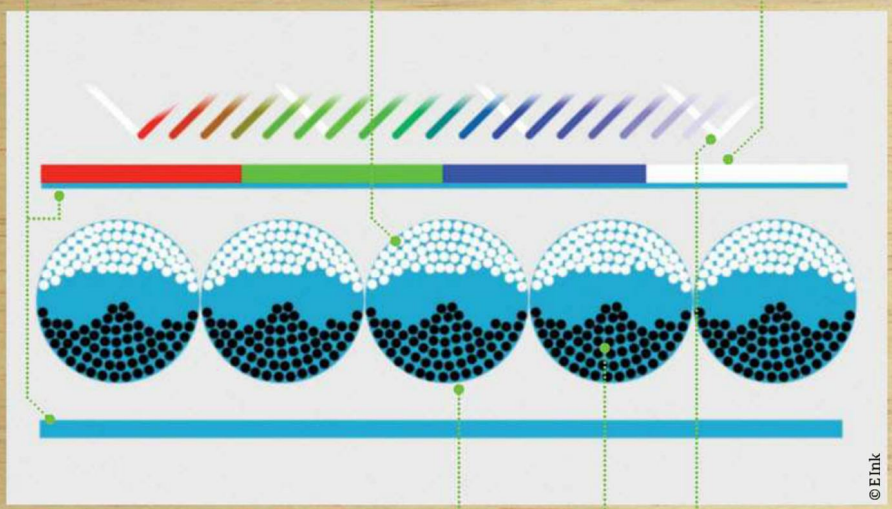
Indeed, just last year tech company Hanvon demonstrated the world's first colour e-ink eReader at the CES trade show in Las Vegas, USA, while over the summer an Apple patent proposed an e-ink/LCD hybrid display.

Here, we explore the anatomy of a colour e-ink display to see how it reproduces vibrant, technicolour images.

Triton imaging film
Layers of super-thin, transparent film sheets enclose thousands of micro-capsules.

Electrical charge
By sending an appropriate electric charge through the micro-capsules, either the black or white pigment particles can be forced to rise to the top.

RBGW filter
To provide colour, an RBGW colour filter is placed on top of the Triton imaging film. Therefore, when white particles rise to the top, the user perceives colour.


© E Ink



© Barnes & Noble

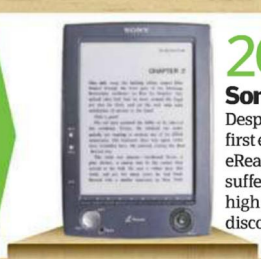
Micro-capsules
Sandwiched between the film, micro-capsules the size of a human hair are used to hold microscopic pigment particles.

Ambient light
There is no backlight in e-ink displays, with pigment particles illuminated by ambient light alone. As such, there is no glare when viewing the screen.

Microscopic pigment particles
Black and white pigment particles provide a polarised colour palette within each capsule, which can be changed by an electric charge.

The evolution of eReaders

We take a look at the development of digital reading devices over the past five years



2006
Sony PRS-500
Despite being one of the first e-ink-powered eReaders, the PRS-500 suffered from a slow UI and high price point. It was discontinued in 2007.



2007
Amazon Kindle (first edition)
The first e-ink device to crack the mass market, the Kindle was quite stylish, compact and great value.





1. TRENDSETTER

NOOK Color
Barnes & Noble's reader comes with a seven-inch, screen, 8GB of memory and an 800MHz Cortex-A8 processor. It weighs in at 448g (15.8oz). Cost: $199.



2. MOST MEMORY

iPad
The fourth-generation iPad has a 9.7-inch screen, up to 128GB storage and a quad-core processor. It weighs 601g (21.2oz). Cost: £399/$499.



3. LIGHTEST

Kindle Fire
Amazon's Kindle Fire packs a seven-inch, 1,024 x 600 screen, 8GB of memory and a dual-core TI OMAP 4 processor. It weighs 414g (14.6oz) and runs a custom version of Android. Cost: $199.

DID YOU KNOW? *The Kindle Fire's operating system is a heavily modified version of the Android 2.3 OS*

NOOK Tablet

Take a peek inside the NOOK Tablet from Barnes & Noble

The NOOK Tablet, launching off the back of Barnes & Noble's NOOK Color – arguably the first device to splice a traditional eReader with a tablet computer – is being released head to head with the Kindle Fire. Offering improved hardware, a dedicated app store, email client, in-browser Flash support, social-networking tools, audio-visual support for interactive eBooks, a new user interface and multiple entertainment services including Netflix, Hulu Plus and Pandora, the NOOK Tablet is a diverse platform for all types of content consumption. It is a million miles away from the brand's basic eReader origins.

Barnes & Noble, like Apple, has also embraced the push towards cloud computing in the NOOK Tablet, with integration of the online content store NOOK Newsstand that allows users to access and download a wide variety of digital publications. This service enables content to be immediately acquired and, in many cases, at reduced cost to the paper equivalents. This has been made possible thanks to the Tablet's utilisation of an IPS LCD screen, allowing colour images, graphics and video to be displayed unlike on a traditional eReader's monotone e-ink panel.

Display
Content is viewable on a seven-inch, 1,024 x 600px IPS LCD display. The panel is a capacitive, multitouch touchscreen. It does not use e-ink.

Processor
As the new NOOK offers the functionality of a full-blown tablet computer, it is fitted with a 1GHz TI OMAP4 dual-core CPU.



© Barnes & Noble

Storage
Storage is delivered by 16GB of internal drive space, as well as the ability to add up to 32GB more via a microSD card.

The statistics...

NOOK Tablet

- **Cost:** $250
- **Content source:** Barnes & Noble
- **App store:** NOOK Apps
- **Screen size:** 7 inches
- **Screen resolution:** 1,024 x 600px
- **Size:** 206 x 127 x 12mm (8.1 x 5.0 x 0.48 inches)
- **Weight:** 399g (14.1oz)
- **OS:** Custom Android Build
- **Storage:** 16GB
- **Processor:** 1GHz TI OMAP4 (dual core)
- **Battery life:** 9 hours

Barnes & Noble NOOK Tablet

Support
The NOOK Tablet supports EPUB, PDF, DOC, DOCX, XLS, PPT, TXT, JPEG, GIF, PNG, BMP, MP3, AAC and MP4 file formats.

Software
Users of the NOOK can access the Barnes & Noble Books store, NOOK Apps and its own magazine and newspaper-centred service Newsstand.

CLOUD CONSUMPTION

Accessing your multimedia content is easier than ever thanks to the rise of cloud-based services

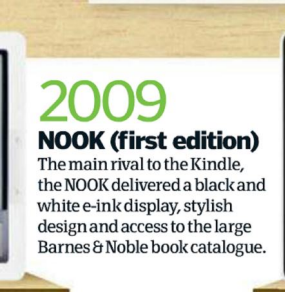
1 Local device
Both the iPad and Fire support cloud-based content consumption, allowing media to be shared over multiple devices. Purchase a book via Apple's iBookstore service on an iPad and it will automatically be pushed to your iPhone and/or iMac.

2 Content store
Key to accessing content is the original source of the media. For example, eBooks acquired through the Kindle Store can be accessed via the Kindle Cloud Reader or by re-downloading the title in-app from the account.

3 In-app
A major benefit the Kindle Store has over Apple's iBookstore is the Kindle app. This means a book can be read on your Fire, your iPad or your Android tablet simply by launching the Kindle app within the OS.

4 Cloud cache
The amount of storage and available functionality on offer from cloud services depends on supplier and cost. Apple's iCloud grants users 5GB of free storage, however for extra space, additional charges are applicable.

5 Load sharing
Cloud computing is not just about remotely hosting and streaming content, but also sharing workloads. For example, Amazon Silk utilises the cloud to speed up the time to display pages by sharing out subsystem processes.



2009
NOOK (first edition)
The main rival to the Kindle, the NOOK delivered a black and white e-ink display, stylish design and access to the large Barnes & Noble book catalogue.



2010
Apple iPad
Along with iBooks, the iPad brought eBooks to the tablet. But its lack of e-ink display and locked-down catalogue meant Kindle won out in the battle of the eReaders.



2010
NOOK Color
Addressing the original's deficiencies, Barnes & Noble introduced colour to its eReader. By ditching e-ink for LCD, many reviews bemoaned increased glare.



2011
Apple iPad 2
Partnered with iOS 5 and the Newsstand, Apple broadened the eReader capabilities of the iPad, allowing newspapers and magazines to now be read in full colour.

"Improvements include a 1,280 x 800px HD display, a front-facing camera and a miniHDMI out port"

Inside the Kindle Fire HD

We lift the lid on Amazon's tablet to see what makes it tick

The original Kindle Fire device was launched in November 2011 as a mini-tablet version of the Kindle eReader. A year (and considerable commercial success) later and Amazon has launched the Kindle Fire HD – a tablet which now has more in common with the likes of the iPad and co than its humble eReader ancestor.

Improvements on the 17.8-centimetre (seven-inch) screen version include a 1,280 x 800 pixel high definition display, a front-facing camera and a miniHDMI out port that allows for output to a bigger display. So what enhancements have been made to the hardware inside the Kindle Fire HD to power all this new technology?

At the heart of the device are a 1.2-gigahertz, dual-core CPU, a 307-megahertz GPU and 16 gigabytes of internal memory(a 32-gigabyte option is also available) for storing hundreds of games, dozens of movies or thousands of books and music files.

This hardware is the base on which an adapted version of the Android Ice Cream Sandwich operating system is supported. It's intended as an improved gateway to Amazon's extensive catalogue – the books, videos, music and also games available for download via Amazon.com. Technically the Kindle Fire HD is an Android device, but the operating system has been so heavily modified it's like a bespoke Amazon media hub.

There are two other versions of the new Kindle Fire HD: both have a bigger 22.6-centimetre (8.8-inch) screen with a 1,920 x 1,200 pixel resolution, faster processor and graphics and a greater standard storage capacity. The high-end version also boasts 4G LTE cellular network compatibility, although commercial 4G networks are still under development in some countries.

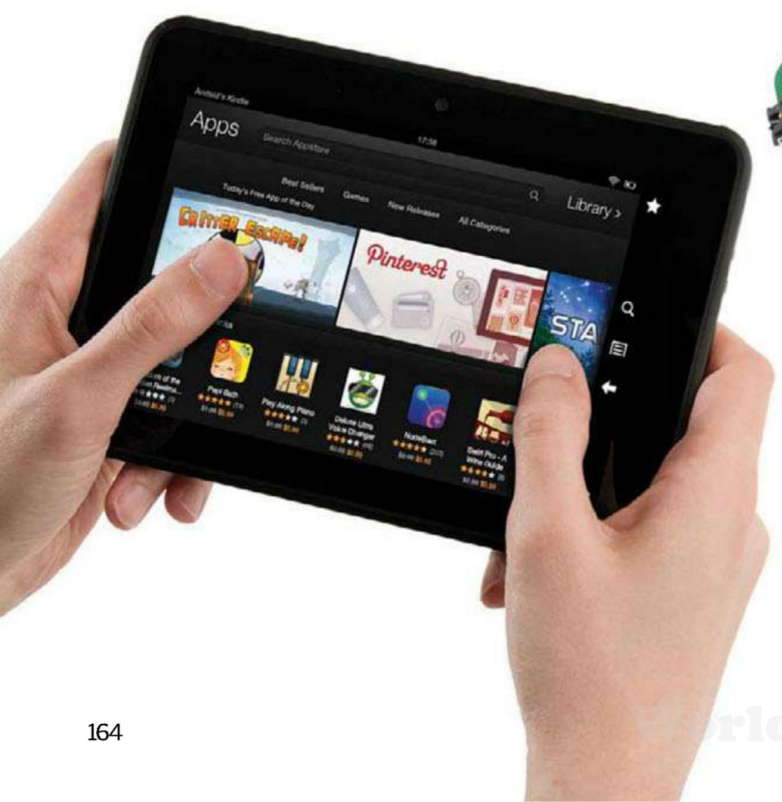
Tablet teardown

What technology lies inside this cutting-edge tablet from Amazon?



Speakers
Customised dual-driver speakers work alongside bespoke audio optimisation software to deliver excellent sound quality.

Camera
The Kindle Fire HD has a front-facing HD camera that takes images at the device's native 1,280 x 800px resolution.





Headphone jack
Nothing remarkable about this 3.5mm (0.14in) jack, except it's standalone, so it's easily replaced if damaged.

Display
The 17.8cm (7in), 1,280 x 800 capacitive touchscreen is fused into a single piece.

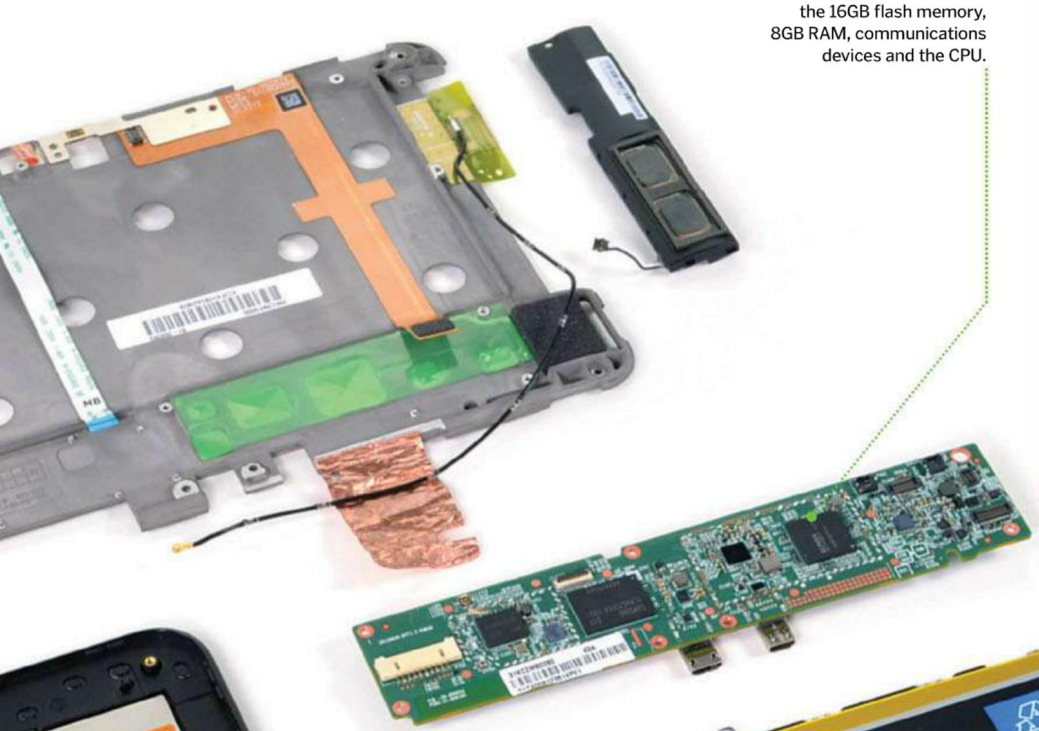
WorldMags.net

THE STATS
KINDLE FIRE HD

CPU 1.2GHz | MAXIMUM STORAGE 32GB | BATTERY LIFE 11 hours
WEIGHT 395g | OS Android 4.0x | DISPLAY 178mm

DID YOU KNOW? *The Kindle Fire HD includes sponsored adverts, but by paying a little extra these can be removed*

Motherboard
The mainboard is home to the 16GB flash memory, 8GB RAM, communications devices and the CPU.





Battery
This lithium-ion 4,400mAh battery powers the Kindle Fire HD for up to 11 hours and takes up most of its internal real estate.

Capacitance controller
This is the Atmel maXTouch mutual capacitance controller – it determines which area of the screen is being touched.

What is in-plane switching?

The Kindle Fire HD screen is made of toughened Gorilla Glass (which is stronger, lighter and more scratch resistant than standard glass) and is capacitive touch sensitive, just like the Kindle Fire. Both have another cool trick though: in-plane switching (IPS) panel technology.

This invention was designed for liquid crystal displays (LCDs) to solve a number of problems that included slow response times, poor viewing angles and bad colour reproduction. A screen with IPS technology doesn't distort, brighten or leave a tail when touched and dragged – clearly a vital feature in any touchscreen device.

It works by rearranging and switching the molecules in the liquid crystal layer (which is just a few micrometres thick and lies between the glass substrates) so that they're parallel to the plates. The previous TN (twisted nematic) display technology has been around in various forms since LCD was invented in the early-Seventies.

Ice Cream Sandwich

Android is the mobile operating system that began with a beta in 2007 and became a commercial OS in September 2008. It's found great success, with over 400 million active devices using it in 2012. There have been four major revisions since version 1.0 and, since Android 1.5 Cupcake in April 2009, each new iteration has been named after a sweet or dessert. The current version of Android is 4.2 (Jelly Bean), though the Kindle Fire HD uses version 4.0.x, or Ice Cream Sandwich (ICS). Like its predecessors, the software development kit it's based on is a version of the open-source Linux OS that's been adapted for modern mobile devices. In turn, Amazon has taken ICS and created an operating system bespoke to the Kindle Fire HD, which streamlines the Amazon media experience and enables Amazon to lock out any features surplus to requirements.



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From the display options to bespoke apps and how it is mounted, the Pebble is all about customisation

Next-generation smartwatches

Explore some of the innovative technology which is taking the humble timepiece to a whole new level

The Pebble concept is a smartwatch that can communicate with any Android or iOS device using Bluetooth wireless technology. It can alert you to incoming calls or emails with a silent vibration, display text messages from a smartphone (these are known as push notifications) on its face, or control music on your phone. All you have to do to set up these features is download the Pebble app to your device – but believe it or not, these are just a few of its basic functions.

The Pebble also has app functionality, such as the pre-installed golf rangefinder and GPS cycling application that enables you to monitor speed and distance travelled. This technology itself isn't new and watches already exist with similar hardware solutions (for example, GPS hardware manufacturer Garmin offers a range of wristwatches with dedicated speedometer features). But via a smartphone the Pebble watch can download many more apps and run several of them on a single device, with software development kits (SDKs) available to give developers full control of the watch and create entirely new Pebble apps. It's similar to the process in which smartphone developers can create apps for the iPhone or an Android phone and then upload them to communal stores.

Another key selling point of the smartwatch is the electronic paper (ePaper) display, which is similar to the eInk screens on modern eReaders, like the Kindle. It can be customised to show the face of your choice: a classic clock face, digital or more conceptual design and you can even design your own watch face if you wish. But undoubtedly the ability to switch between a range of functions other than just telling the time has to be the Pebble's biggest draw.

What is IFTTT?

Building on its smartphone communications and simple push notifications, the Pebble watch has employed the IFTTT ('if this then that') service. This is an internet communications tool that works via **ifttt.com** to build connections and allow websites and social media to generate messages under certain conditions, using personal accounts as well as public profiles. The user creates an account and then generates a 'recipe' with the 'if this then that' statement – 'this' being the trigger and 'that' the action to take. IFTTT currently can access 60 channels that include Twitter, Facebook, LinkedIn and various email accounts, with the trigger being anything from a keyword in a tweet to an attachment in an email. For example: if you add a new photo to Instagram, it can automatically pass into your Dropbox account. The recipe can be changed so a notification is sent to the Pebble when this happens, or if you're tagged on Facebook, or if a certain person emails you, etc.

KEY DATES
ONES TO WATCH

1940s
The first slide-rule watches with logarithmic scales in addition to timekeeping (right) start to appear.



1975
Pulsar brings out the world's first calculator watch with a stylus for its tiny buttons.

1982
Seiko launches the D409 memory watch with its 112 bytes of memory for storing calculations.

1991
Swatch brings out the Beep, a modified watch that accepts pager messages.



2006
Garmin introduces the improved Forerunner 205 athlete training watch (left) with more sensitive GPS.

DID YOU KNOW? *A recent patent for a flexible, wrist-mounted device filed by Apple suggests an 'iWatch' isn't far off*



Evolution of smartwatches

Historically, the definition of a 'smartwatch' has been a watch that has functionality beyond merely timekeeping. So, at the time in the Seventies and Eighties, Nintendo's game wristwatches (a watch with a built-in LCD game) or Casio's famous calculator watches were the first smart forerunners.

Of course they have evolved with the rise of computing, GPS and mobile phones to include radios, thermometers, compasses, heart-rate monitors and more. With the miniaturisation of consumer technology, they can now include cameras, be used as mass storage devices and even serve as media players. A combination of the latest technologies comes together to create today's smartwatches that act more like a mobile wrist computer than the one-trick timepiece of yesteryear.

Microchip processors for modern watches easily compete with the CPUs found in desktop machines of the late-Nineties, the wide availability of GPS means the wearer can easily navigate and track speed, while Bluetooth and other communications technologies enable the watch to tap into boundless other resources beyond its own physical capabilities.

Inside the Pebble

We tear apart this state-of-the-art watch to see what makes it tick



Button
The Pebble's buttons are spring-loaded and incorporate gaskets to remain watertight.

Casing
The housing is sealed and waterproof up to five atmospheres in both fresh and saltwater.

Vibration motor
When activated by a message or other programmed trigger, this module vibrates the watch.

Motherboard
The nerve centre of the Pebble contains an accelerometer, a 120MHz ARM chip and 32MB of serial flash memory.

ePaper
The display uses a Sharp Memory LCD for a 144 x 168px ePaper display.

Ribbon cable
This strip supports the four buttons, three LEDs and Bluetooth 2.1 antenna.

Display film
This covers three LEDs that act as a backlight for the whole watch face.

Power
A 3.7V, 130-milliamp, USB-rechargeable battery allows for over seven days' use on a single charge.

Screen
Both scratch and shatter resistant this covers the display and also features an anti-glare coating.

© iFixit.com; Pebble

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"Once melted, the chocolate is drawn into a hollow cylinder that extends upwards from the bowl"

How do quartz watches work?

Keep accurate time with nothing more than a lump of rock

The quartz watch uses a special quality of the crystal (actually made of a silicon dioxide compound) that was discovered to vibrate at a very regular 32,768 times per second. Clocks and watches that utilise quartz are generally very accurate but they do lose and gain time; this is because the crystal reacts to changes in the atmosphere such as shifts in temperature and pressure.

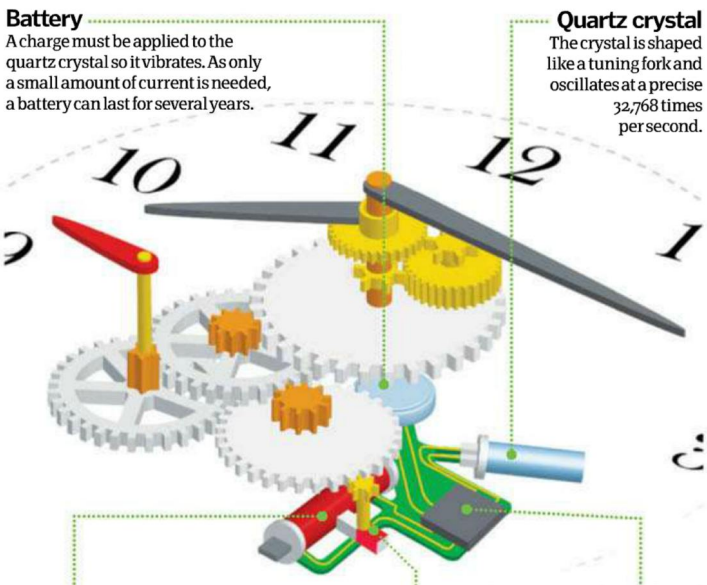
Quartz watches work because the crystal itself is piezoelectric, which means it vibrates when you apply an electrical current to it. The circuit that the quartz crystal sits at the heart of also collects the energy that the piezoelectric effect generates to drive the motor that moves the hands or, alternatively, power the LCD display if it's a digital display.



The first quartz wristwatch was the Astron by Seiko in 1969

© Seiko

Inside a quartz watch





Fun, tasty and all thanks to Ancient Greek physics!

How do chocolate fountains flow?

An ancient principle is the key to this decadent way of enjoying chocolate

Chocolate fountains use a mechanism known as the Archimedes screw to transfer liquid chocolate to a higher plane. To melt the chocolate a heating element is positioned within the base of the device, below a metal bowl that acts like a reservoir for the liquid chocolate. Once it's melted, the chocolate is drawn into a hollow cylinder that extends upwards from the bowl.

Inside the cylinder is a helical threaded screw mechanism powered by a small motor. The motor turns the screw, enabling liquid to be transferred from the bottom up along the screw until it reaches the top. When the liquid arrives at the summit of the pipe it empties out over a series of tiers – usually two or three – before cascading as a uniform chocolate curtain back down into the bowl below where the whole process can begin again.

Inside the chocolate fondue device



© Sephra Europe

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THE STATS
LASM BAZOOKA

RANGE 500m (1,640ft) WEIGHT **4.4kg (9.7lb)**
CARRY LENGTH **78cm (31in)** FIRING LENGTH 98cm (39in) PREP TIME **8 secs**

DID YOU KNOW? *The Tugaslugabed alarm clock, circa 1910, awoke sleepers by pulling a loop of string attached to one toe*

Bazookas explained
How personal grenade and rocket launchers work

During World War II there became a clear space on the battlefield for personal rocket-propelled grenade launchers, missile launchers and the like. Advances in tank armour and grenades whose blast radius exceeded the distance soldiers could throw them meant the bazooka was an invention waiting to happen. And it did: fielded by the Americans in 1942, it was a basic beast consisting of a wired tube and pistol grip. The rocket was loaded and connected to the weapon's ignition wiring from the open rear end by one soldier, while another aimed and fired.

Modern 'bazookas' are specialised for use against personnel, tanks and even buildings. The British Army currently uses the light anti-structures missile (LASM) for urban warfare. The missile is loaded into a telescopic, disposable launcher designed for single use.

The rocket comprises a warhead, fuse and a propulsion unit and, when the trigger is pulled and the rocket fired, spring-loaded fins deploy to stabilise its flight while the force of its propulsion enables it to penetrate the target structure before its explosive payload is detonated.

The Panzerfaust 3



Advanced warheads
Advanced varieties include the PzF 3-IT, for tanks with reactive armour, and the Bunkerfaust, for bunkers, light armour and soft targets.

Sight
The sight mounted on the top of the Panzerfaust 3 is telescopic and can be reused.

Launcher
The main body is designed to be used once and discarded after launch, although the firing and sight units can be reused.

Standard warhead
The standard Panzerfaust 3 is equipped with a hollow charge warhead that can penetrate 700mm (28in) of armour.

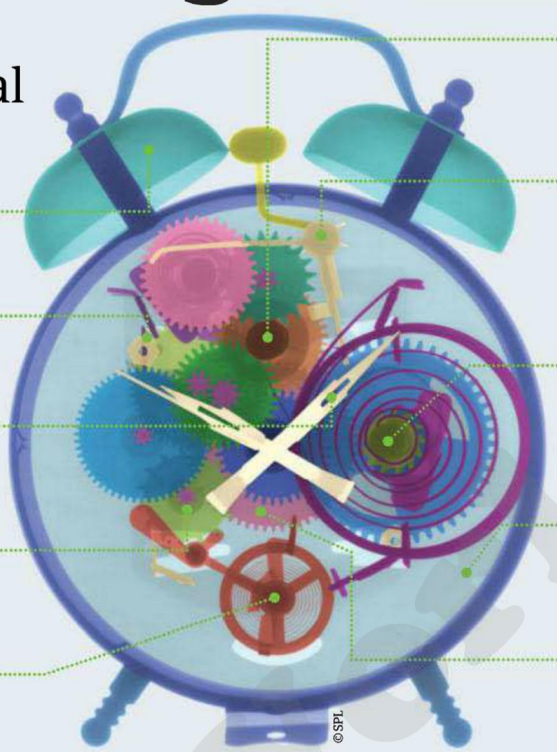
Propulsion
The back of the launcher is filled with plastic granulate that gives the warhead an effective range of 20-400m (65-1,312ft).

©sonaz2006



The original M1 bazooka could penetrate armour up to 76mm (3in) thick

Inside an analogue alarm clock
What makes these mechanical time machines tick?



Bell
The majority of analogue alarm clocks use metal bells to provide a loud ringing sound.

Power
The various mechanisms inside analogue clocks are powered either by batteries or DC electricity.

Hands
The hands of the clock are connected to concentric shafts at the centre of the clock where gears turn them at different speeds.

Time
The gears inside control the hands of the clock. An oscillating wheel ensures the gears move consistently at the same speed.

Main wheel
Analogue clocks, like wrist watches, use an oscillating wheel to turn the clock's hands.

Synchronised
With every second that passes, a chain of wheels synchronises the gears and operators to ensure they accurately track the motion of time.

Ring
An extra hand is used for the alarm. A spring is pressed against the mechanism of the bell hammer and, when the alarm time comes around, tension in the spring is released, causing the hammer to strike the bell(s).

Alarm
There are a further two gears for the alarm hand, which activate the spring when the correct rotation corresponding to the set time has been reached.

Dozen
In all there are about 12 moving elements in an analogue clock.

Gears
Four gears between the spring and the main wheel are responsible for turning the hands of the clock.

©SPL

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"Colour is introduced to the image by the LED's white light being broken down into RGB via a prism filter"

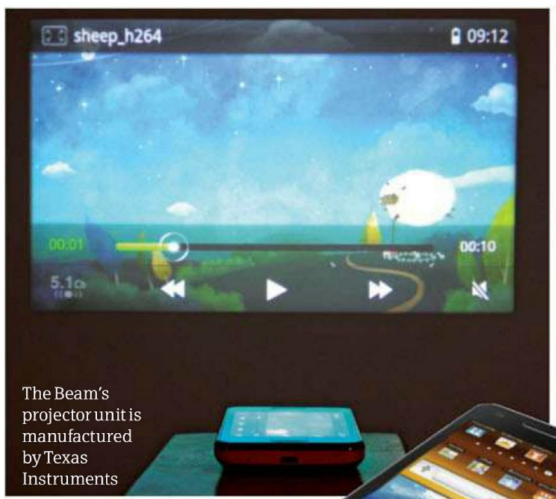
Inside the Galaxy Beam

How does this smartphone device double up as a video projector?

Samsung's Beam is one of the latest smartphones in the manufacturer's Galaxy range of devices. The phone itself offers a 10.2-centimetre (four-inch) TFT screen, 1GHz dual-core CPU and the usual list of connectivity and storage options. However, what separates it from the pack is that it also comes equipped with an integrated projection system capable of blowing up the screen's display to a rather sizable 127 centimetres (50 inches).

The projector's integration is possible due to it being based on the advanced Digital Light Processing (DLP) system made by Texas Instruments. This differs from standard units as it can reflect a binary data pattern (video or image) with a speed, precision and efficiency greater than most spatial light modulators. It achieves this through a revolutionary array of 2 million tiny mirrors, or digital micromirror devices (DMDs), each of which is just one-fifth the width of a human hair. The hinge-mounted mirrors are controlled via bit-streamed binary data entering the DMD unit from the DLP processing chip, the information ultimately dictating their angle of tilt.

The Beam uses a single white LED as a light source. This illuminates the DMD mirrors, which – adapting to the pixel arrangement of the video/image that's embedded in the code – individually tilt so the pattern is replicated – each mirror acting as a real-world pixel. So if a specific pixel in the image needs to be black, the corresponding DMD mirror would tilt away from the light source. Colour is introduced to the image by the LED's white light being broken down into RGB via a prism filter prior to reaching the mirrors. As such, upon leaving the device, a colour, highly detailed image can be reproduced from just binary data.

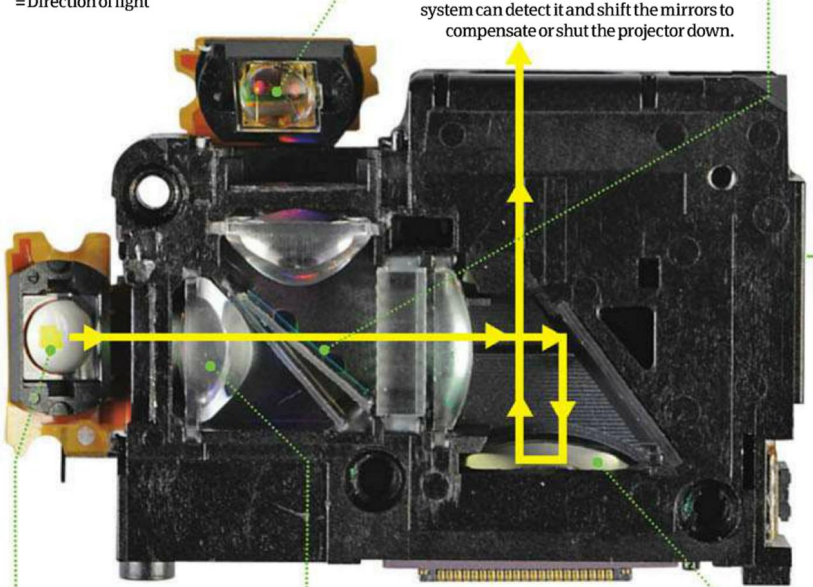


The Beam's projector unit is manufactured by Texas Instruments

Anatomy of the DLP projector

Take a closer look at the Galaxy Beam's primary feature

= Direction of light



Infrared transmitter/receiver
As the Beam's projector is housed within a plastic casing (rather than invar), an infrared transmitter and receiver are also included. These are used to monitor the system's optical path length in the event of the heat or humidity creating lens displacement. If this occurs the IR system can detect it and shift the mirrors to compensate or shut the projector down.

Filter
On its own the DMD unit reflects white light into light, dark and grey pixels. For colour to be added, prior to the white light from the LED reaching the DMDs, it must pass through a wedge mirror prism to be split into RGB.



Light
For the DLP system to work a light source is needed (for the DMDs to reflect). In the Beam's DLP system a single white LED is used.

Optics
For the light from the white LED to be focused correctly it must pass through a series of lenses. This ensures it hits the DMDs just so and is therefore projected correctly on leaving the device.

DMD unit
The DMD unit is a rectangular array of 2 million hinge-mounted microscopic mirrors, each just one-fifth the width of a human hair. The bit-streamed image code entering the DMD unit from the DLP chip directs the mirrors' movement so that each reflects either a light, midtone or dark pixel.

© Chipworks; Samsung

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How do calculators do the maths?

Electronic calculators make use of an impressive array of tech to crunch the numbers

Tapping numbers into a calculator is extremely easy, with your numerical query answered in seconds. However, with each sum a series of complex processes and components come into play underneath the plastic casing of your trusty calculator.

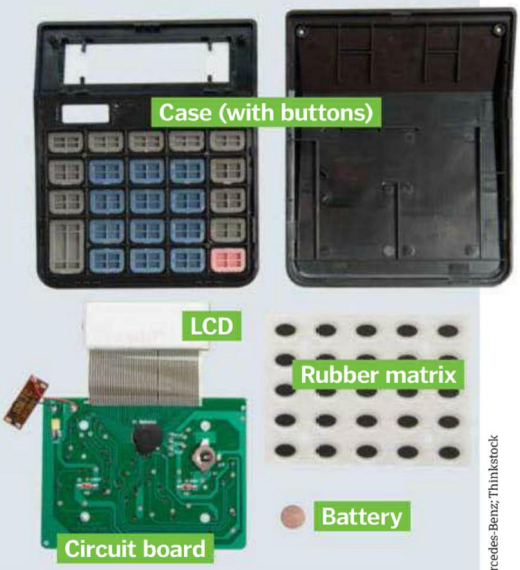
Components first. A standard calculator includes a plastic casing, rubber button matrix, circuit board, single-chip CPU, battery array and liquid crystal display (LCD). More advanced models come equipped with a solar cell stack and/or integrated memory chips – the former used to charge the internal battery with the Sun's energy, and the latter to store advanced calculations or equations.

Now let's move on to the processes. Take a sum such as '2 + 2'. When a user presses the number 2 button on the rubber matrix, it deforms, forcing a bottom-mounted electrical contact onto the circuit board below and creating a connection. This causes electricity to flow to a pair of transistor switches on the board that then convert the current into an on-off binary equivalent (a combination of 1s and 0s).

Next, when the '+' button is pressed, the inputted 2 is stored in its binary form by the calculator's CPU, before resetting the input state to a receptive position. After the next 2 is inputted, the CPU sends both numbers to a logic gate as soon as the '=' sign is hit.

Logic gates are electrical circuits with two inputs and only one output which execute logical operations that, in this context, are the adding, subtracting, multiplying and dividing processes. The inputs are sent in binary form to a logic gate, processed and then outputted as a single output – ie the number 4 in binary code.

Finally, the answer is routed to the device's LCD, where the digit 4's binary is converted into segmented, illuminated lines that can be read off the display bar.



© Mercedes-Benz; Thinkstock

Fitness bracelets explained

The ultimate workout gadget that keeps exercise stats close to hand

Fitness monitors are flooding the market promising to keep you informed and, ultimately, get you fitter. But while some gadgets are fine-tuning a new generation of champion, there's a niche new strain making eyes at the underbelly of the sporting world.

The Nike+ FuelBand, for one, is primed to motivate the mighty indifferent. It's driven by a three-axis accelerometer, which measures motion, acceleration and gravitational pull to gauge the exact type of activity undertaken (using an algorithm developed via a classification exercise). This, together with the level of exertion and duration, is converted into 'NikeFuel', for an instant appraisal.

The 'movement' reading from the accelerometer is also used alongside the user's height, weight and gender to accurately calculate calorie burn. So whether you're working out at the gym or merely leafing through the sports pages, the FuelBand will know how much energy you expend, and in theory coax you towards a preset target.

The FuelBand is also able to sync to a smartphone via an app for viewing and/or sharing your progress, while sensors can measure ambient light and automatically tweak the display's brightness to suit.

Nike+ FuelBand key features

A quick tour around the intuitive accessory that keeps tabs on your daily activity



2x © Nike

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"Uses for 3D printers are varied, with applications in the military, medical, industrial and commercial spheres"

3D printers explored

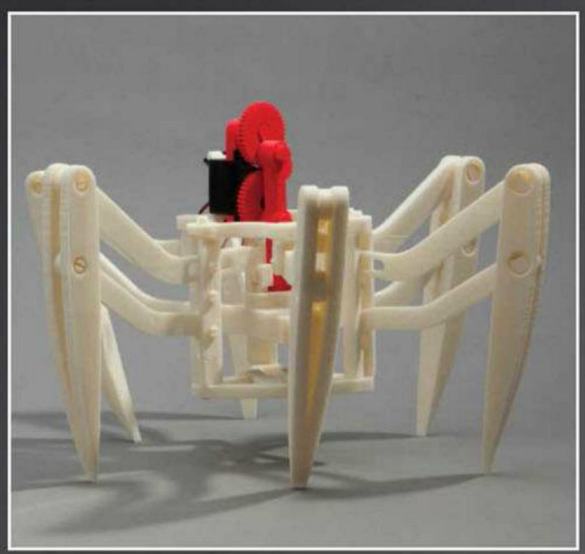
How do these clever machines take printing to another dimension and what is their potential for the future?

3D printing is the manufacture of a physical three-dimensional object by the layering of two-dimensional cross sections, one on top of the other. The layers are fabricated through the solidifying and binding of a build material – such as polylactic acid (PLA) – from a liquidised/powder state, with a series of heaters, nozzles and cooling units. The result of this cross-sectional layering is that solid and hollow items can be created by simply inputting the desired object's dimensions into the 3D printer.

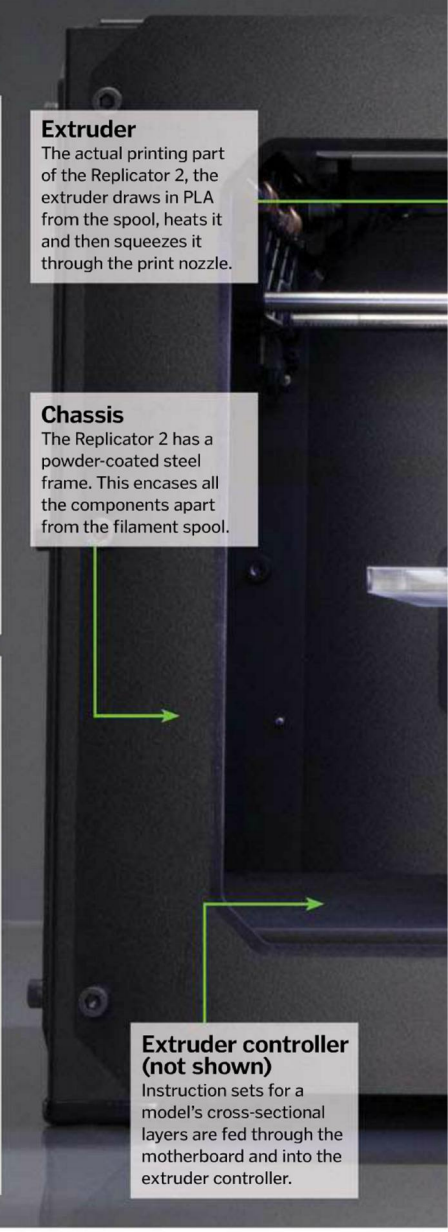
The design schematics for 3D printer models come from computer-aided design (CAD) files, with a virtual model parsed into thousands of cross sections, which become instructions for the printer's control units. This data dictates exactly where to deposit the material in each layer, with the process taking place on a stable, non-stick surface called the build plate.

Uses for 3D printers are extremely varied, with applications in the military, medical, industrial and commercial spheres. A good example of this is the use of 3D printing in the prototyping of new machine components. Here complex designs for intricate parts can be quickly and cheaply constructed out of biodegradable plastic, trialled in a test machine and then tweaked if necessary.

While previously 3D printing has largely been confined to large-scale operations due to high cost, in the last five or so years desktop 3D printers aimed at enthusiasts have emerged. These allow anyone to feed a printer with designs from their PC – banks of online designs exist – or a memory card, and make models at home. One such DIY printer is the MakerBot: Replicator 2, which we look at closely here.







Extruder
The actual printing part of the Replicator 2, the extruder draws in PLA from the spool, heats it and then squeezes it through the print nozzle.

Chassis
The Replicator 2 has a powder-coated steel frame. This encases all the components apart from the filament spool.

Extruder controller (not shown)
Instruction sets for a model's cross-sectional layers are fed through the motherboard and into the extruder controller.

History of 3D printing

We reveal how this industry has come on leaps and bounds over the past few decades...

1976
Inkjet is born
The inkjet printer's invention opens up the possibility of printing objects through layering a liquefied material.

1984
Chuck goes stereo
American engineer Charles 'Chuck' Hull invents stereolithography, a printing process that allows 3D objects to be created from digital data.

1992
Prototype
Charles Hull's company 3D Systems makes the first commercial stereolithographic 3D printing machine.

1993
MIT
Scientists working at the Massachusetts Institute of Technology (MIT) first coin the term '3D printing'.

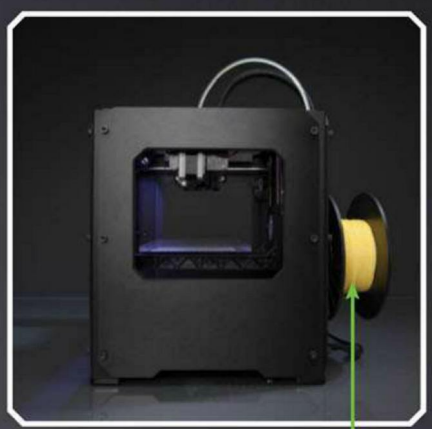
2002
Printing organs
Scientists use 3D printing technology to engineer a miniature but functional kidney that is able to filter blood. Organ printing takes off.

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DID YOU KNOW? *In February 2013 plans for a structure on the Moon built in part by 3D printers were revealed*

Replicator 2 up close

What technology enables this printer to produce objects in three dimensions?



Cooling fan
An active cooling fan within the Replicator 2 cools the liquefied PLA as it leaves the print nozzle. This means it solidifies quickly and evenly.

Print nozzle
This is the opening on the end of the extruder from which the heated PLA filament emerges to be deposited onto the build plate. The nozzle has a diameter of just 0.4mm (0.015in).

Filament spool
An auxiliary spool that is fitted to the rear of the Replicator 2. This holds the polylactide filament and ensures it is fed evenly into the extruder.

Gantry
The extruder is secured to a gantry in the top of the chassis. The extruder runs on the gantry left to right to allow for precise positioning for each layer.

Z-axis rod
The threaded metal rod that runs down the back centre of the Replicator 2 enables the build platform to move up and down to various heights.

LCD panel
The Replicator 2's LCD display shows important diagnostics and system status, and is where the build platform's levelling process is controlled.

Build platform
The support for the build plate, where the PLA is deposited. The build platform can be level adjusted to suit each printing project.

The statistics...



MakerBot Replicator 2

- **Height:** 38cm (14.7in)
- **Width:** 49cm (19.1in)
- **Depth (no spool):** 32cm (12.8in)
- **Weight:** 11.5kg (25.4lb)
- **Operating temperature:** 15-32°C (60-90°F)
- **Power supply:** 100-240V
- **Chassis:** Powder-coated steel
- **Nozzle diameter:** 0.4mm (0.015in)
- **Filament diameter:** 1.75mm (0.069in)
- **Layer resolution:** 100-340 micrometres (0.004-0.013in)

2005
The RepRap race
British academic Adrian Bowyer founds RepRap, an open-source initiative to build a 3D printer that can print most of its own components (right).



2008
Thingiverse
www.thingiverse.com launches as an open-source depositary in which people can upload and share CAD files for 3D models.

2009
Making history
MakerBot Industries starts shipping 3D printers, which focus on ease of use and low cost. 3,500 units have sold by 2011.



2011
Flying high
Engineers at the University of Southampton, UK, design and fly the world's first 3D-printed aircraft.

2012
New jaw
Doctors in Holland 3D print a prosthetic lower jaw for an 83-year-old woman. It is implanted successfully.

© MakerBot Industries; Julianh72

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"Both types of glasses ideally ensure that each eye only ever sees one stream of footage"

Active vs passive 3D glasses

See through the technology that enables us to watch films in three dimensions



Both active and passive 3D glasses are used with display devices that show a movie as two offset streams of imagery. For a viewer, essentially this means that each eye receives slightly differing information, which – without conscious thought – the brain combines to form a sequence of three-dimensional images.

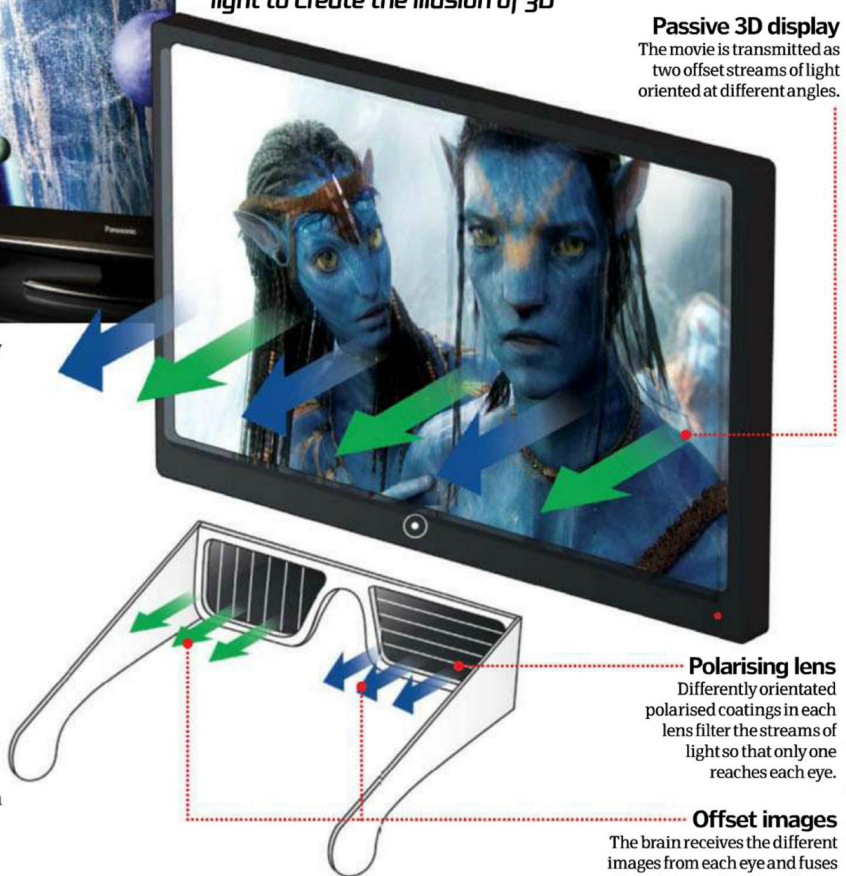
However, the method that the glasses employ to achieve this differs somewhat. First, with active shutter 3D the streams are displayed as an alternating sequence of matching frames so rapidly that it looks like they are transmitted together. The glasses respond to wireless signals from the display device by applying voltage to a liquid crystal layer in each lens successively. This basically makes the lenses 'wink' at the speed at which frames are swapped.

Passive 3D glasses, on the other hand, have no circuitry and essentially just filter light. Passive displays show two streams of images simultaneously as light waves aligned at different angles. The glasses act as polarising filters that reflect back the light wave matching the alignment of their polarisation.

If working correctly, both types of glasses ideally ensure that each eye only ever sees one stream of footage and the brain does the rest of the work, fusing the two streams into a 3D scene.

Polarising 3D

How passive glasses use a trick of the light to create the illusion of 3D

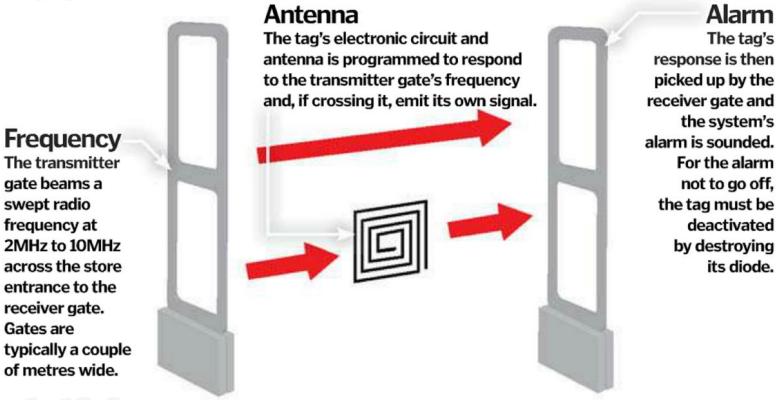


© Thinkstock; Alamy; Panasonic

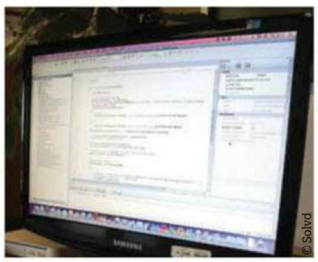
How to stop shoplifters

Used worldwide to stop thieves, security gates use radio waves to sound alarms

Radio frequency security systems work by programming a small, disposable electronic circuit and antenna to respond to a specific frequency, transmitted by one of two security gates. These antennae come in the form of security tags, solid plastic or stickered labels that can be attached to a store's products. The tags are programmed to emit a certain radio frequency, typically right in the middle of the total radio frequency range when activated by the security gates. The gates of the system act as both a transmitter – with a constant swept radio frequency (between 2MHz and 10MHz) projected from one of them – and receiver, with the latter detecting the tag's signal response if activated by the former. Security tags are deactivated when exposed to a strong radio frequency pulse blast (this is what the clerk's handheld scanner at the kiosk is for). The pulse destroys their diode and prevents them from projecting a signal.



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3. Code
Development applications such as MonoTouch, MonoDroid and Xcode are used in tandem with the Apple and Android development kits to develop the app into a working program.

2. Build
Buttons and user interface elements are laid out in an Interface Builder, using programs such as Xcode and MonoTouch to define where and how things are placed.



4. Refine
Once you have a good, solid system working in the iOS or Android developer kit simulator, the app can be loaded onto an iPhone or Android device for testing.

Available on the App Store
© Apple Inc

App development in five steps

Creating your own app is more straightforward than you think...

1. Design
First, you'll need to sketch out how you want your app to look, and then use a stencil tool such as UI Stencils to translate this to an iOS or Android building tool.

5. Submit
An application submission pack can now be created with the digitally signed app and, if approved, the app can be uploaded to the App Store or Android Market for others to download.

How to make an app

From design to submission, how do you make the perfect app?

App development relies on the Apple and Android developer kits and a variety of third-party software to turn your idea into reality. The official developer kits come with most of the software you'll need to make your app, including coding and simulation programs.

The first part of app development is designing how your app will look. For this you'll need stencil equipment, supplied from companies like UI Stencils, to sketch out your app design. These physical templates allow you to sketch the layout of each page to determine button layout, image locations and other information.

Once happy with your design, you'll need to build the app in an Apple or Android environment. This can be done on programs such as Xcode and MonoDroid, which let you code in C, a computer programming language that creates lists of instructions for a program to follow, so you can visibly see the results of your actions. This allows you to build links between pages on your app and assign functions to buttons.

Once you have finished building your app, it must be loaded into a simulator supplied with the developer kit for testing. You can then load it onto your iPhone, iPad or Android device for further debugging, until it's ready to be uploaded onto the App Store or Android Market, following a brief submission process.

Learn more

If you aren't ready to build an app yourself, Solvd Limited provides all the services you'll need to make an app for Android, Windows 7 and Apple devices, in addition to web design and systems consultancy. Find out more at www.solvd.co.uk.

solvd.

Evolving TVs are positioning themselves at the heart of their owner's digital life, offering amazing levels of connectivity, as well as delivering a host of dynamic ways to interact with them

SUPERSMART TVS



It's a well-known fact that technology iterates. It continually gets better, faster and more functional. This is true across all its forms, offering consumers tools and gadgets that can make their lives easier and more enjoyable. Importantly though, what is also true is that more often than not these iterations are merely incremental improvements, offering largely the same product as before but ever so slightly tweaked. Maybe the technology is slightly faster – for example, a 2.6GHz CPU over a 2.5GHz one in a computer – but it is not delivering something radically new; it does not offer a road map for future advancement. At other times, a game-changer comes along. A piece of technology that reaches into the future and pulls back a slice of what's to come – a recent example, arguably, might be Apple's Siri personal assistant.

The smart TV is about to do the same for consumer televisions. By converging the TV's traditional high-resolution display with the computational power, connectivity and software of a PC, as well as the motion-control abilities of next-gen consoles and the type of voice-recognition and command systems made famous by Siri, smart TVs are soon to be the digital heart of every household.

From cloud computing, data storage, email and social networking, on to exercising regimes and games, through to video calling, word processing and weather reports, this new generation of televisions offers users the potential to collapse a plethora of electronic devices into one central hub, streamlining their day-to-day activities and blurring the lines between a work and leisure device. To see how smart TVs are set to accomplish this, we're taking a look at today's most cutting-edge unit, the Samsung ES8000 S8, exploring its hardware, software and features which are transforming the 'idiot box' into something altogether more clever.

5 TOP FACTS
SMART TELEVISIONS

Marketing
1 'Smart TV' is a marketing term to loosely describe a television that connects to the web and sports modern features and functionality such as gesture control.

Perspective
2 Today's top-end smart TVs output at a resolution of 1,920 x 1,080px, which is considered hi-def. However, 4K televisions already exist that more than double this resolution.

Siri
3 One of the hottest rumours currently circulating is that iPhone manufacturer, Apple, is working on a smart TV of its own and intends to incorporate its Siri personal assistant software into it.

Convergence
4 The current shift towards smart TVs is led by the concept of technological convergence, a bringing together of technology found in computers, televisions and set-top boxes into a single unit.

Open source
5 All smart TVs come with their own operating system via which the unit's apps and features may be run. These operating systems are mostly based on Linux or other Android variants.

DID YOU KNOW? *The ES8000 enables users to pull pictures, videos and music wirelessly from a mobile device*

Benefits of a smart TV

Combining the functions of many modern-day appliances, is this the ultimate device?

Personal computer
Smart TVs incorporate components traditionally found in PCs, such as hard drives, processors, memory and cooling fans/panels, letting users store and access media and data files.

Games console
In-built camera motion-detection capabilities, plus a variety of digital app stores, allow games and fitness applications like those demonstrated on Xbox Kinect to be accessed.

Mobile phone
Thanks to the voice-recording and recognition hardware, as well as high-definition integrated web cameras, smart TVs also enable users to make voice and video calls via Skype.



2x © Samsung

HD TV
Of course, smart TVs also mean users can enjoy their usual TV shows in standard-definition, high-definition or 3D, the latter made possible via active-shutter 3D glasses included with most models.

Tablet
Accessing websites via a capacitive touch panel is a key selling point for tablets. The smart TV takes it one step further by making online content accessible via both gesture and voice controls.

The statistics...



Samsung ES8000 58

Width: 1,230.3mm (48.4in)
Height: 722.3mm (28.4in)
Depth: 30.8mm (1.2in)
Weight: 25.4kg (55.9lb)
Screen size: 1,397mm (55in)
Resolution: 1,920 x 1,080px
Display type: LED
Bezel: Aluminium
Power supply: AC220 – 240V (60Hz)

The new remote controls

Samsung's ES8000 typifies an industry-wide push towards gesture control, as well as voice and facial recognition, but how do they work?

The ES8000's ability to be manipulated by gestures is thanks to a motion-tracking camera. The camera automatically detects users in front of the screen and then locates and tracks hand movements. When the TV is on, the user activates gesture control by waving once; this locks the on-screen cursor to the user's hand. Then you can navigate the screen and its options by simply moving your hand. To simulate a cursor select, the user just closes and opens their palm.

While we are talking about the ES8000's camera, it also functions as a recogniser for the set's facial-recognition software. This can be used for Skype video calls, or for a facial login to the user's personal Smart Hub account. As with gesture control, this works by the camera automatically detecting the user's face with a mapping tool, and then matching their characteristics with those calibrated on the set.

Voice control is equally advanced and is made possible by a wireless IR blaster; this is a small cone-shaped peripheral that connects to the TV wirelessly via Bluetooth and communicates with the set-top box (satellite or cable, for example) to grant control over volume and channels, among other things. This is especially important, as without it, the ES8000's voice control would be limited to crude up/down commands.

A selection of pre-programmed instructions each activate different aspects of the television's and set-top box's control schemes. Voice control is initiated by the user saying, "Hi, TV". Once this has been activated, it offers fine management of channel selection, volume and power, as well as several other functions. For instance, if you wanted to change from channel 3 to 27, you'd simply say, "Hi, TV. Channel 27." The voice-control function even lets users vocally log in and out of various accounts and services.



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"Samsung has integrated its own app store – Samsung Apps – directly into the Smart Hub"

Maximum connectivity

Smart TVs offer a direct portal to the internet, creating a whole new way to surf the web

Sharing

One of the top features of Samsung's Smart TVs, the ES8000's AllShare software allows users to push content wirelessly to the screen or pull content off it and on to a smartphone or tablet via a home network. The former works by simply selecting a file from the handheld device, activating the AllShare option on a submenu, and then dictating a destination. As such, if a user has recorded a video on their smartphone, they can quickly share the content with others on the TV's far larger screen. In contrast, the pull feature enables a user to drag specific TV channels from the set's screen on to a tablet, so you don't miss a moment.

Apps

Samsung has integrated its own app store – Samsung Apps – directly into the Smart Hub UI. These apps are largely small tools for streaming content, playing games or accessing online info – eg news sites – rather than the large-scale varieties found on the App Store or Google Play. But due to the customisable nature of the Smart Hub, they can be positioned on the home screen and operated via the ES8000's gesture and voice-control functions.



Video

On-demand and video-streaming services are directly accessible through the Smart Hub or a selection of applications. These allow content to be streamed wirelessly over the internet at 1080p directly on to the screen and, most importantly, without the need for a dedicated TV service provider. The ES8000 is also tailored for video playback from perennially popular sites like YouTube, with all resolution videos capable of being streamed live.

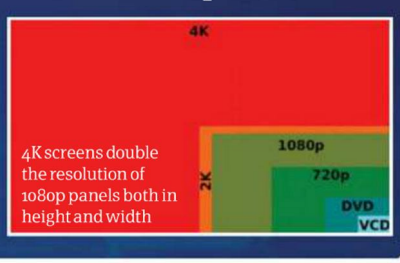
Social networking

Along with a direct internet connection, the ES8000 provides both in-browser access to social-networking sites like Facebook and Twitter, as well as dedicated UI applications. Uniquely though, thanks to the unit's dual-core CPU, picture-in-picture functionality allows these social-networking sites to be open alongside a TV channel, enabling users to comment on programmes as they are being broadcast so they can update their status accordingly.

The race to 5K

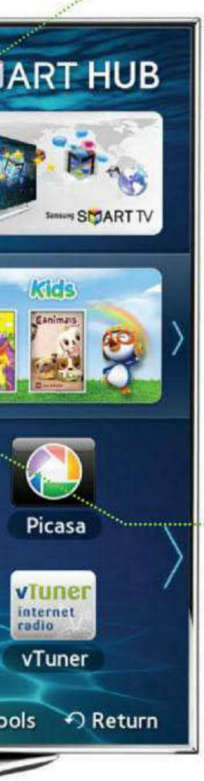
Next-generation TVs are leaving 'HD' resolutions in their dust, doubling and tripling them over colossal panels

While today TVs are marketed on their ability to output images at 'HD' resolutions – maxing out at 1080p (1,920 x 1,080) – the future of consumer products promises far greater resolutions. Indeed, showpiece panels already have been developed that output images at twice, or even three times, those figures. 4K screens – named due to their horizontal resolution of approximately 4,000 pixels – more than double that of 1080p screens, and as such, allow for crisp image reproduction on far bigger units. A good example is the Panasonic TH-152UX1, which delivers 4,096 x 2,160 across a 386-centimetre (152-inch) set. Despite its awesome size and resolution, the UX1 costs $500,000 and is made to order, so screens like this won't be going mainstream anytime soon. Regardless though, the UX1 gives a taste of the current race to 5K – a race that is accelerating at a furious rate due to many filmmakers already shooting on 5K video cameras (such as on *The Hobbit*).



4K screens double the resolution of 1080p panels both in height and width

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© Samsung

Cloud computing

The ES8000 ships with 5GB of cloud storage per user, which can be accessed via the Family Story app. This lets users upload photos, video and audio files to the cloud and store them remotely. As such, the cloud data repository can be accessed by more than just the TV itself, with content accessible via Samsung smartphones and tablets. In addition, these auxiliary devices can also upload content to the cloud repository directly and remotely, enabling, for example, a user to upload photo content while away on holiday and allow another family member – who couldn't make the trip – to access it instantly via the home TV.

Fitness

One addition that makes great use of the ES8000's motion-tracking camera is the Smart Hub's Fitness software. This acts in a similar way to activity-based games released on Microsoft's Kinect console add-on, dictating a wide variety of exercises to complete and then tracking your progress. As the user is exercising, the set's camera generates an artificial mirror, presenting a video stream on an overlay next to their virtual instructor, helping you to copy their actions. This is signed in and out of via the facial login, so individual accounts can be set up.

Is 3D TV dead?

The marketing has largely fallen on deaf ears over the past three years – so does 3D TV have a future?

'3D TV' currently relies on a user wearing one of three types of 3D glasses: anaglyphic, polarised or alternate-frame sequencing. The former two are passive technologies, using a series of filters to encode an image for each of the eyes to generate a mild 3D effect, while the latter is an active technology and the one currently being taken up by smart TVs. This active sequencing works by opening and closing minuscule shutters in the glasses to alternately present an image to the left and right eyes in sequence. These glasses do this so rapidly that the perceived 2D images fuse into a single 3D one.

Critically, however, all of these technologies have certain issues. First, for any user to perceive a 3D effect they need a pair of glasses, which are often very expensive. Second, the glasses – if active – require batteries to operate, adding to the lifetime expense of the unit. Third, all types darken the viewed images dramatically, leading to less vibrant pictures or requiring the television to overcompensate, outputting images at incredibly bright and saturated levels.

The future of 3D, however, is far from over, with a new push to produce glasses-free 3D TVs. These prototype models adopt an evolved form of the autostereoscopy used in the Nintendo 3DS games console, but, unlike the 3DS, they allow 3D to be perceived at more than one central viewing angle. These sets do this in a variety of ways, but the one with most traction so far is a motion-tracking camera, which follows a viewer's eyes and repositions the 3D effect accordingly.



Right now high-end smart TVs come bundled with active-shutter 3D glasses

© Panasonic

Semiconductor heaven

Bells and whistles aside, the advanced circuitry is the real brains of smart TVs



© Chipworks

Conexant voice recogniser

Voice recognition on the ES8000 comes courtesy of a Conexant voice input processor, which is positioned along with the circuitry needed for sound reproduction on a secondary board.

Wi-Fi module

While the ES8000 has an Ethernet input for a hard-wired internet connection, it also comes with a Ralink 5572N Wi-Fi module, which allows the set to connect wirelessly to the user's router too.

Digital Natural Image engine

The DNIe chip uses four proprietary processes – a motion optimiser, contrast enhancer, detail enhancer and colour optimiser – to boost image and sound quality.

Expansion port

This TV comes with a rear-mounted expansion port, which is included to allow its firmware and hardware to be augmented with an evolution module in the future. This means that the set can be upgraded periodically.

LCD timing controller

The timing controller chipset optimises the screen's pixel refresh timing, ensuring the generation of consistent image reproduction at all times.

Frame rate controller

The SDP1111 frame rate controller allows the LED panel to produce over 16 million colour shades through dithering, a method that combines adjacent pixel colours for shade simulation.

As we have seen, the ES8000 S8 Smart TV from Samsung offers a boatload of next-generation features, ranging from motion and voice control, through cloud computing and on to an app-tacular Smart Hub user interface. Importantly though, all of these rely on – and indeed would be useless without – a selection of advanced physical hardware, which luckily the S8 has in spades.

In fact, when you take the unit apart, it's easy to see how this device is significantly more advanced than a stock HD TV. From memory modules and application processors through to imaging technology, the ES8000 is stuffed with some hot semiconductor tech. All over the main board, which is housed in a pure aluminium shell – as well as over a brace of subsidiary ones – a mountain of silicon can be found, plus a couple of items that even use the latest generation of 32-nanometre high-k/metal-gate (HKMG) material. Take a look at the teardown for some of the key components of this awesome hardware.

"The ES8000 Smart TV is stuffed with some hot semiconductor tech"

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HOW IT WORKS

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The technology behind everyday life



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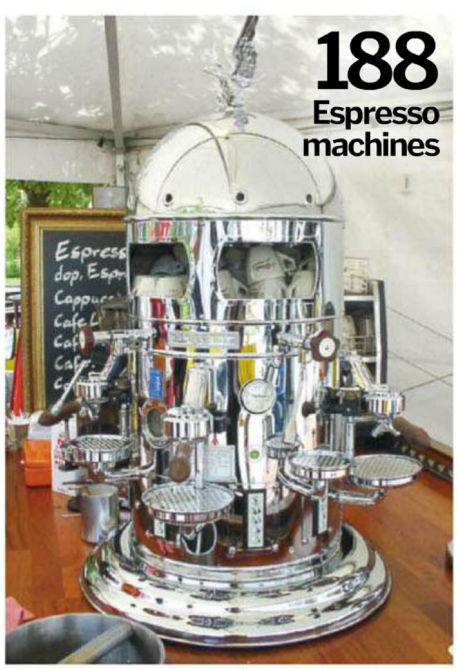
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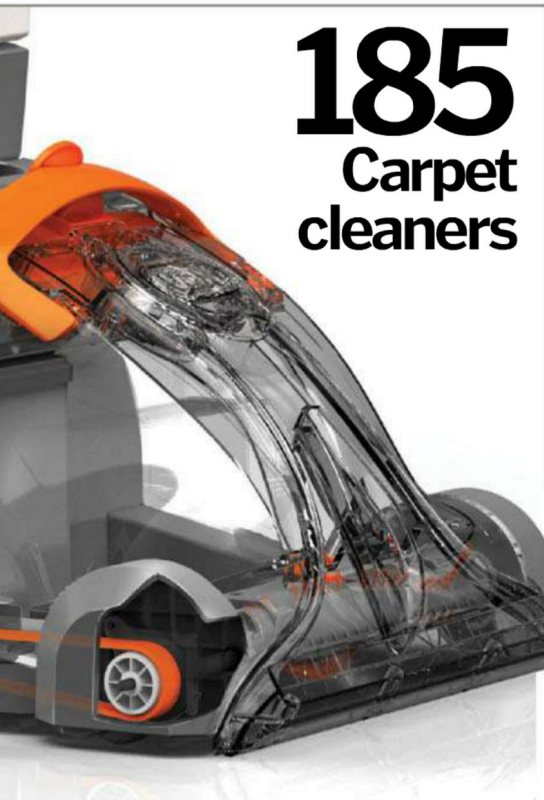
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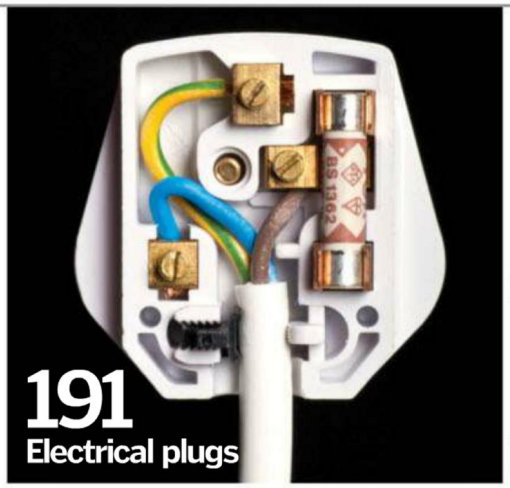
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"Cyclonic vacuums separate dust by exposing the dirt-filled air to large centrifugal forces"

How bagless vacuum cleaners work

The humble vacuum cleaner has undergone a serious makeover. Learn how these everyday devices keep our homes spic and span

Vacuum cleaners work in a variety of ways, each largely dependent on the type of suction and filtering methods adopted. However, within the modern vacuum cleaner market, three main systems dominate, each using differing suction, separation and filtering techniques and technology.

The first common type is the direct fan variety, which can either use a bag or canister for dust storage. Direct fan vacuums suck up dirt through a large impeller mounted close to the brushbar – the cylindrical brush typically located at the front-bottom of the appliance – or suction opening. The dirt is agitated, ie drawn, out of the carpet or other surface through the impeller and then deposited into the device's storage container, either directly or through a filter. These units are generally used for industrial cleaning purposes, as they generate a high-volume, low-energy consumption airflow, however due to their low suction power and basic filtering system, they're not so well suited to the domestic environment.

The second main type of vacuum is the cyclonic variety. These differ significantly from direct fan types, as instead of separating dust with a series of impellers and bag filters, they do so by exposing the dirt-filled air to large centrifugal (ie moving away from the centre) forces. This works by the cleaner sucking in airborne dust into a specialised collection vessel at a specific angle (at a tangent). This process forces the air to generate a fast-spinning vortex, which



Shell
The ball's outer shell is made from glass-reinforced polypropylene, which both provides protection for all internal components and aids smooth manoeuvring.

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5 TOP FACTS VACUUM CLEANERS

Sweeper
1 The first vacuum cleaners were called carpet sweepers and relied on elaborate, bellows-based mechanisms to generate suction. They manually swept up dirt and dust with rotating brushes.

Dyson
2 Today the foremost name in the vacuum industry is Sir James Dyson, a British engineer famed for creating bagless vacuum cleaners. It took him 5,000 prototypes to perfect.

Roomba
3 A recent addition to the market is the iRobot Roomba series of robotic cleaners. These small, circular devices use a variety of sensors to periodically clean a user's home automatically.

Filtration
4 Vacuum cleaners can use a variety of methods to filter gathered dust, ranging from traditional material-capturing bags to water filters and cyclonic separation.

Suck-cess story
5 After Dyson perfected his bagless cleaner, every vacuum manufacturer rejected it. Dyson set up his own company and is now worth £2.69bn ($4.2bn), according to Forbes.

DID YOU KNOW? *The first vacuum cleaner was patented by US engineer Daniel Hess in 1860*

through its centrifugal force, causes the dust particles trapped within it to move to the outside of the vessel. The dirt, once freed from the air vortex, then falls to the base of the container through gravity for later disposal. In addition, due to the dust being separated without using a bag or extensive series of filters, cyclonic vacuums can boast very high suction levels. As such, they are very popular in residential markets, as their continuous high levels of suction enable various attachments for particular tasks to be used with little to no loss of airflow.

The third and most recent addition to the vacuum market is the robotic vacuum cleaner. These small – often circular – devices operate automatically by analysing a room with a variety of positional, acoustic and visual sensors and then proceed to periodically sweep its floor. These units typically use impellers, compressed vacuum bins and a series of filters to draw in fine particulate dirt through their bottom-mounted brooms and brushes, before storing it internally for later manual extraction. Due to the small-scale nature of these vacuum cleaners, they are commonly used for small residential or medical applications, however their suction volume and intensity matches neither direct fan nor cyclonic types and they do not generally accept attachments either which limits their usefulness.

Each of these three systems, as mentioned, uses one or more filters to remove particulate dust and dirt from the air, which all vacuums exhaust directly back into the immediate environment. These filters include standard bags, finely perforated paper or cloth containers, water tanks, plastic meshes, charcoal sheets and HEPA (high-efficiency particulate arresting) traps. Often, a combination of these filters is used within any given device, playing to each of their strengths. For example, charcoal sheets are especially good at removing odour particles, while HEPA traps specialise in capturing minuscule particles (as tiny as 0.3 micrometres).

The statistics...

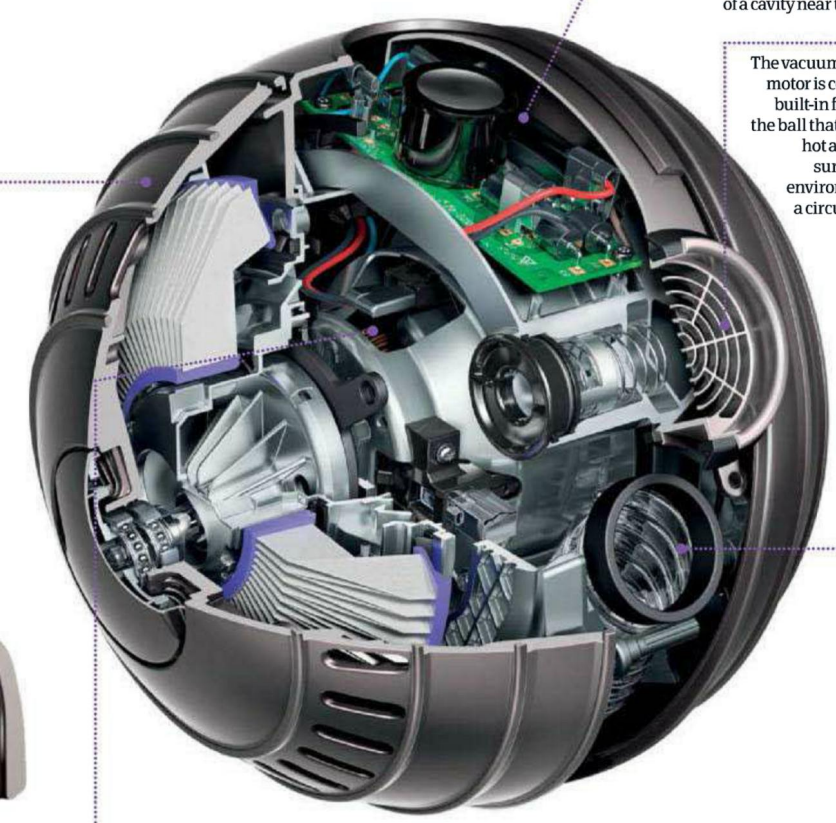
DC41 Animal



Height: 1.07m (3.5ft)
Width: 0.39m (1.3ft)
Depth: 0.34m (1.1ft)
Weight: 7.8kg (17.2lb)
Filtration: Cyclonic
Suction power: 255 AW
Movement type: Ball pivot
Head type: Motorised brushbar
Bin capacity: 2.1l (0.46ga)

Inside Dyson's DC41 Animal

The Dyson Ball is at the core of the DC41 vacuum, but what tech does this pivotable sphere conceal?



Cabling
The ball has also been designed to house the Animal's power cable, which extends into and out of a cavity near the motor.

Fan
The vacuum's electric motor is cooled by a built-in fan within the ball that transfers hot air into the surrounding environment via a circular series of vents.

Motor
A small electric motor lies at the heart of the ball and is used to power the fans, turbines and brushes of the DC41 Animal.

Ducts
Air drawn in through the brushbar and/or suction hose is routed through the ball itself through a series of ducts and into the bin.



Why is cyclonic cleaning so effective?

A landmark breakthrough in vacuum cleaner tech, cyclonic separation and filtration grants both power and efficiency

1 Intake
Dirt-containing air is routed into the collection vessel via the brushbar or suction hole and thrown against its outer wall at a tangential angle.

2 Vortex
A vortex is generated by the air's movement within the central bin, forcing large dirt particles and dust to be prised free and spun to the sides of the vessel.

3 Bin
The dirt, once free from the bin vortex, falls down the sides to the base of the container where it is stored. Typically, this bin can be manually removed by the user and simply tipped out with the general rubbish.

4 Filter
The remaining air – which may still be contaminated with fine dust – is then passed through an internal filter, trapping further dirt that may have been missed.

5 Mini-cyclones
Finally, the air is drawn up through the centre of the vacuum into a series of cyclones. Again the air is routed at a tangential angle, however their smaller size generates a higher velocity spin and allows even the smallest dirt particles to be captured, and again dropped into the bin below.

4x © Dyson

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"As water cannot be squeezed, when pressure is applied it will naturally proceed to a zone of lower pressure"

How do pressure washers work?


Key elements of any power washer include pressure, heat, the cleaning solution and water flow rate

Why does blasting grime with pressurised water get rid of the dirt that soap alone can't shift?

The basic mechanics of a pressure washer involve squeezing pressurised water through a series of small openings to create a powerful jet of liquid that's capable of dislodging dirt and grime from hard surfaces such as patios, walls and vehicles.

Domestic pressure washers are connected to the mains water supply by a hose attached to an intake valve on the outside of the washer. When the unit is switched on, the motor spins an angled swash plate at over 3,000 revolutions per minute. This swash plate is used to transform circular motion into reciprocating (up and down) motion to drive spring-loaded pistons up and down; it is these pistons that are responsible for drawing water into the contraption.

Every time the wide end of the angled swash plate passes, it pushes down on the top of the pistons, causing them to descend. Conversely, when the thin end of the plate passes, the pistons then rise back up to their original positions. The rising of the pistons draws water into the pump through a one-way valve. Because water cannot be squeezed, when pressure is applied it will always naturally proceed to a zone of lower pressure. Therefore when the piston falls and starts to press down on the water that's just entered the pump, the liquid must escape through another one-way valve – this time exiting into the outlet hose under a great deal of force.

The high-pressure water travels at speed along the outlet hose until it hits the closed trigger in the gun. Here the water is blocked – and the motor is temporarily interrupted. When the trigger is pulled by the operator, the motor starts up again, channelling a steady jet of high-pressure, high-speed water out through the tiny hole in the nozzle.

This model from Kärcher's wide range of domestic pressure washers features a reservoir for detergents, which have the added benefit of breaking down the dirt further. It also boasts a water-cooled motor, which helps it perform more efficiently.

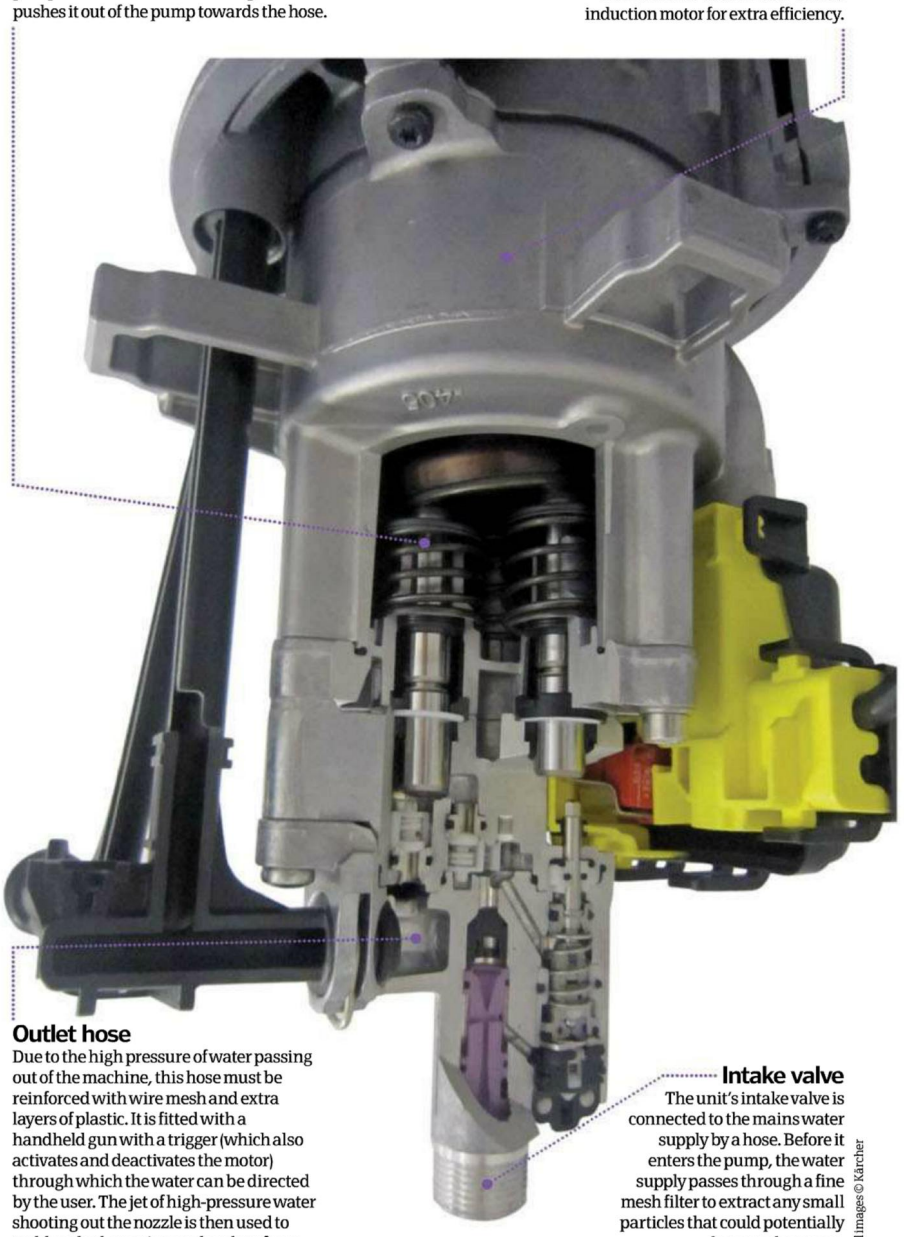
Under pressure

As the name suggests, pressure is what drives these machines, but what is it? Pressure is the force applied to a solid, liquid or gas, which causes a substance's molecules to be squashed. The pump in a pressure washer increases the pressure on the liquid, causing the water molecules to bunch together. Unlike air, however, water cannot be compressed, so the crowding water molecules push against the walls of the container. If the fluid can move, when the pressure increases, the molecules have to move towards any point where the pressure is lower; in the case of the pressure washer that means through the outlet valve. Power washers can bump up the pressure of a typical garden hose by 15-50 times, or even more.

Inside the pressure washer's pump

Spring-loaded pistons
Powered by the motor, the pump is driven at high speed to draw water in. This one features a three-piston axial flow pump, which works like a suction pump that draws water in through one end and pushes it out of the pump towards the hose.

Electric motor
The pump inside the pressure washer is driven by a motor that is fed by the mains electricity supply. This model from Kärcher uses a water-cooled induction motor for extra efficiency.



Outlet hose
Due to the high pressure of water passing out of the machine, this hose must be reinforced with wire mesh and extra layers of plastic. It is fitted with a handheld gun with a trigger (which also activates and deactivates the motor) through which the water can be directed by the user. The jet of high-pressure water shooting out the nozzle is then used to tackle caked-on grime on hard surfaces.

Intake valve
The unit's intake valve is connected to the mains water supply by a hose. Before it enters the pump, the water supply passes through a fine mesh filter to extract any small particles that could potentially damage the pump.

All images © Kärcher

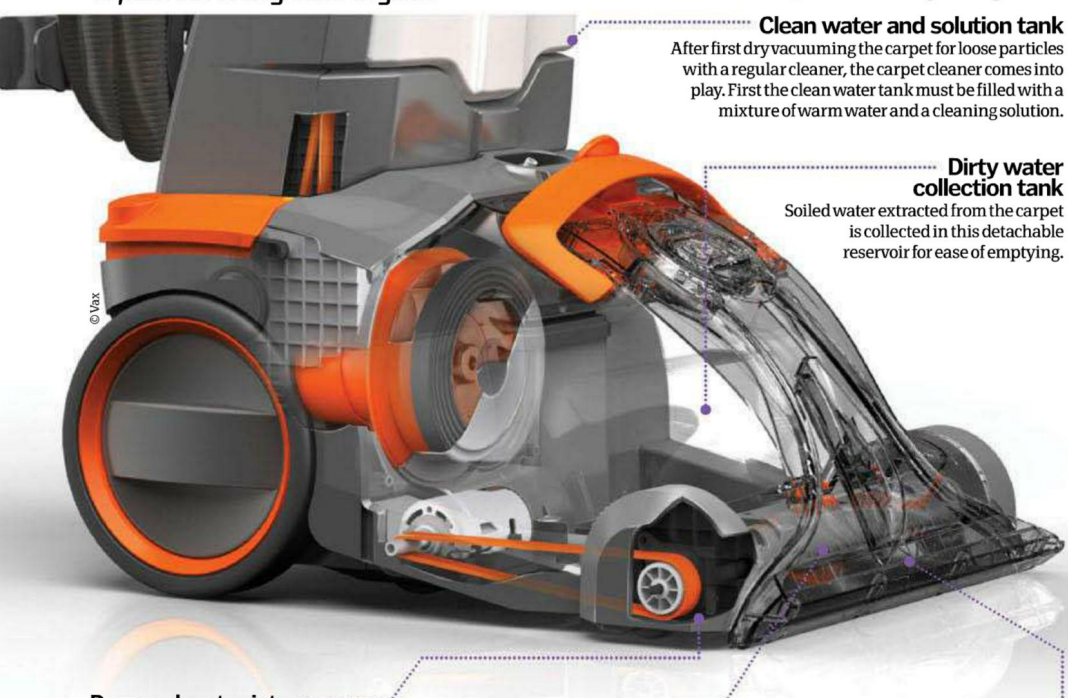
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Carpet cleaners

How these machines shampoo your carpets and upholstery to get them looking as good as new

Inside the Vax Rapide Ultra 2

This wet carpet and upholstery cleaner uses high-powered jets to pump the water and detergent into a material to flush out even ground-in grime



Clean water and solution tank
After first dry vacuuming the carpet for loose particles with a regular cleaner, the carpet cleaner comes into play. First the clean water tank must be filled with a mixture of warm water and a cleaning solution.

Dirty water collection tank
Soiled water extracted from the carpet is collected in this detachable reservoir for ease of emptying.

Powered water jets
When using the device, a trigger in the handle dispenses a consistent amount of detergent that is then pumped by high-powered jets from the clean water tank deep into the carpet. With the trigger activated, the device is pushed forward by the user and the cleaner will be applied to the area covered.

Rotating brush bar
The rapidly rotating brush bar aids cleaning as it helps to lift the carpet fibres, enabling the swift extraction of dirt from all directions while also grooming the fibres leaving them soft and bouncy.

Suction technology
Once detergent has been pumped into the carpet on the forward stroke, releasing the trigger and pulling the machine backwards sucks the now dirty water back into the machine via two V-shaped channels. This technology – called Dual V twin air path suction – is used in this Vax model to ensure even and consistent suction.

In addition to just sucking up dust and other surface dirt from the pile in your carpets and furniture, specialised carpet and upholstery cleaning machines can also remove deeper stains and other grime, using either wet or dry techniques.

Wet cleaners employ the use of either steam or chemicals to kill germs and pick up dirt and remove stains. Hot water or steam is most effective at breaking down the grime as applying heat destroys the structure of microbes so they cannot survive. These wet variants work by first adding clean water to a dirty carpet. The water is then absorbed by the muck before being sucked back up by the machine with powerful suction technology. It's important not to get the carpet too wet, however, as depending on the solution used, this can alter the colour, and even shrink it in the case of wool-based carpets.

Dry cleaners, meanwhile, deposit a dry chemical on to the carpet, which is then absorbed by the dirt and sucked back up by the cleaner, but this type is less effective at giving a heavily soiled carpet a really deep clean. Because these cleaners apply a strictly controlled amount of moisture this can ensure the carpet remains virtually dry.

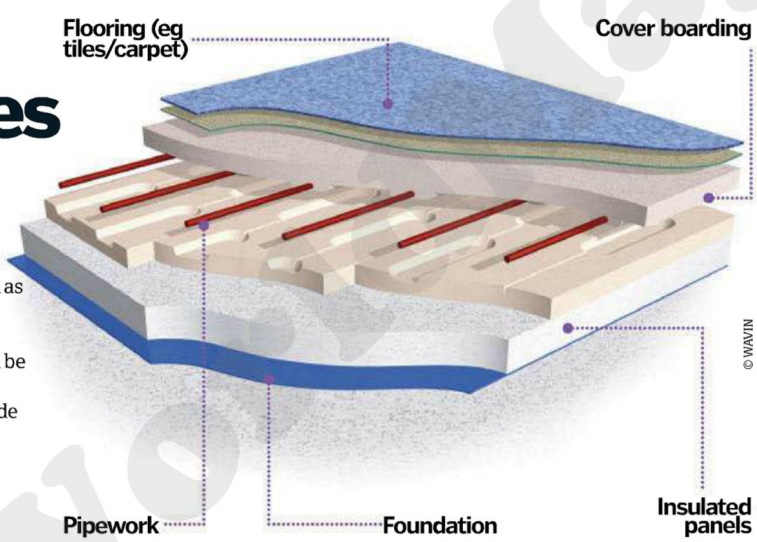
How underfloor heating heats homes

What is this economical and efficient way of keeping our homes toasty?

Traditional wall-mounted radiator heating systems convect heat into the room, sending heat towards the ceiling in a circular cycle. In contrast, underfloor heating consists of electric elements, or water pipes, that radiate heat up evenly throughout the whole room. For optimum efficiency, a thermostat in each room can monitor and control the temperature.

Underfloor heating is also unobtrusive and easier to maintain as the elements, or pipework, can be embedded in concrete floors when houses are constructed, or they can be fitted under existing flooring.

A saving of 20 per cent can be made on fuel bills, and for buildings with high ceilings, savings can reach as high as 40 per cent compared with traditional heating systems.



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"Autotaps are more economical and eco-friendly and are ideal in hospitals"

What's inside a dishwasher?

This time-saving kitchen appliance is a far more complex machine than it first appears

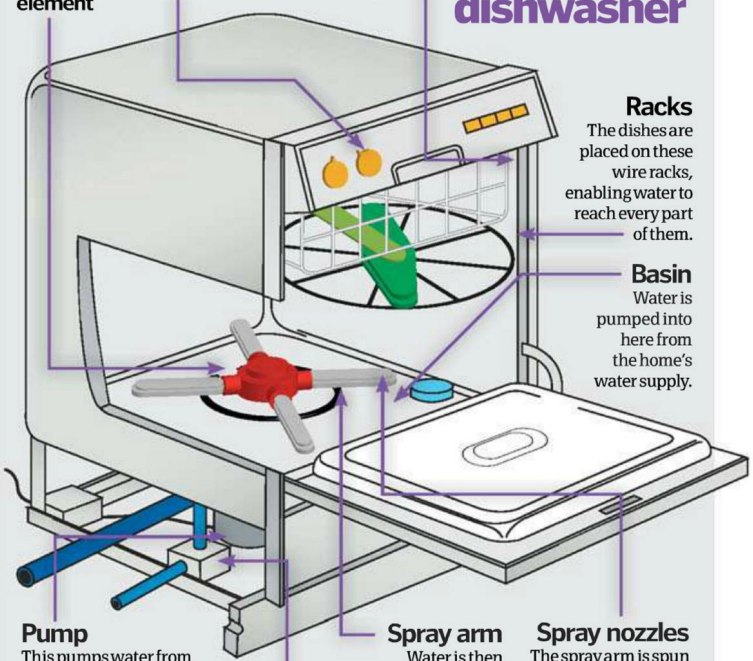
Dishwashers use a combination of pressure, heat and gravity to clean your dishes. A small basin fills with water at the bottom of the dishwasher and a heating element heats the water. It's then pumped up and out into a T-shaped spray arm with a series of nozzles running along its length. The water is sprayed from these nozzles and the arm is spun by a motor to cover as much surface area as possible.

An automated timer, often located in the door of the dishwasher along with the controls for the heating mechanism, reverses the pump after a set amount of time. Water is then drained out of the dishwasher and fresh water is pumped through to rinse the dishes. Finally, air is heated inside the dishwasher to dry its contents.



They don't just get cleaned by magic...

Inside your dishwasher



The tech behind automatic taps

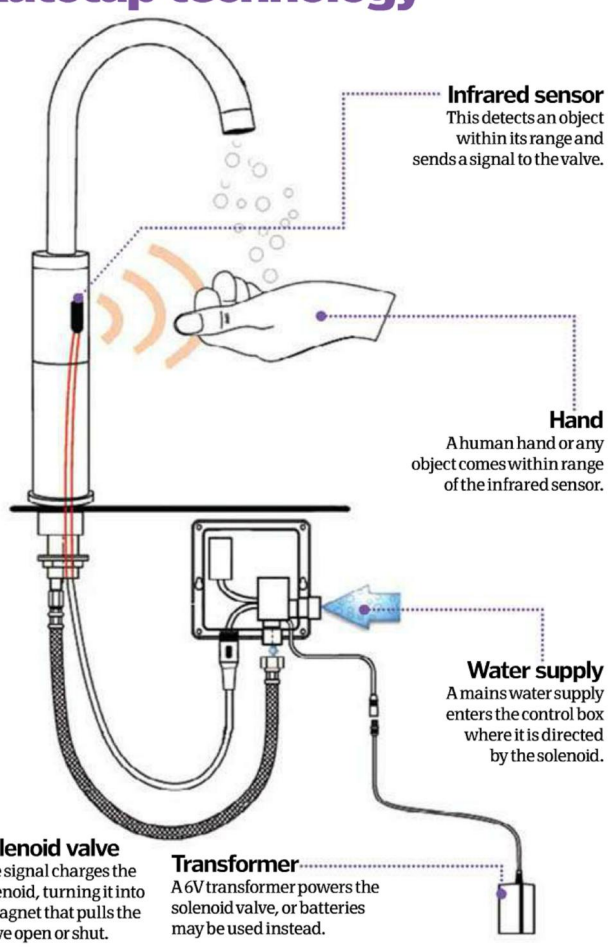
How autotaps differ from classic faucets and why they're better

It's often the case that inventing technology that makes our lives easier has some kind of karmic effect on the planet. Like the combustion engine, for example: millions of us get from A to B in a car every day, yet it's one of the major contributors to global pollution.

Not so with automatic taps. This relatively recent invention enables us to pass our hands under the spout and immediately douse them in water, without twisting a knob. An infrared sensor detects when an object (eg hands) is in front of the tap and sends an electric signal to a solenoid valve. This wire coil acts as a magnet when a current is passed through it, lifting a valve into the range of a permanent magnet that holds it open, allowing water to flow. Once the object is removed, the sensor sends another signal to the solenoid valve, which reverses its polarity and pulls the valve shut, stopping the flow of water.

Automatic taps are not only more economical and eco-friendly but they are also ideally suited to places such as hospitals, where germs can easily be transferred via communal surfaces.

Autotap technology



©www.autotaps.com

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5 TOP FACTS
TOILET TECH

Lav
1 'Lavatory' comes from Latin 'lavatorium', which comes from 'layo', which translated to modern English means 'I wash'. Today, the word describes a washing/bathing area.

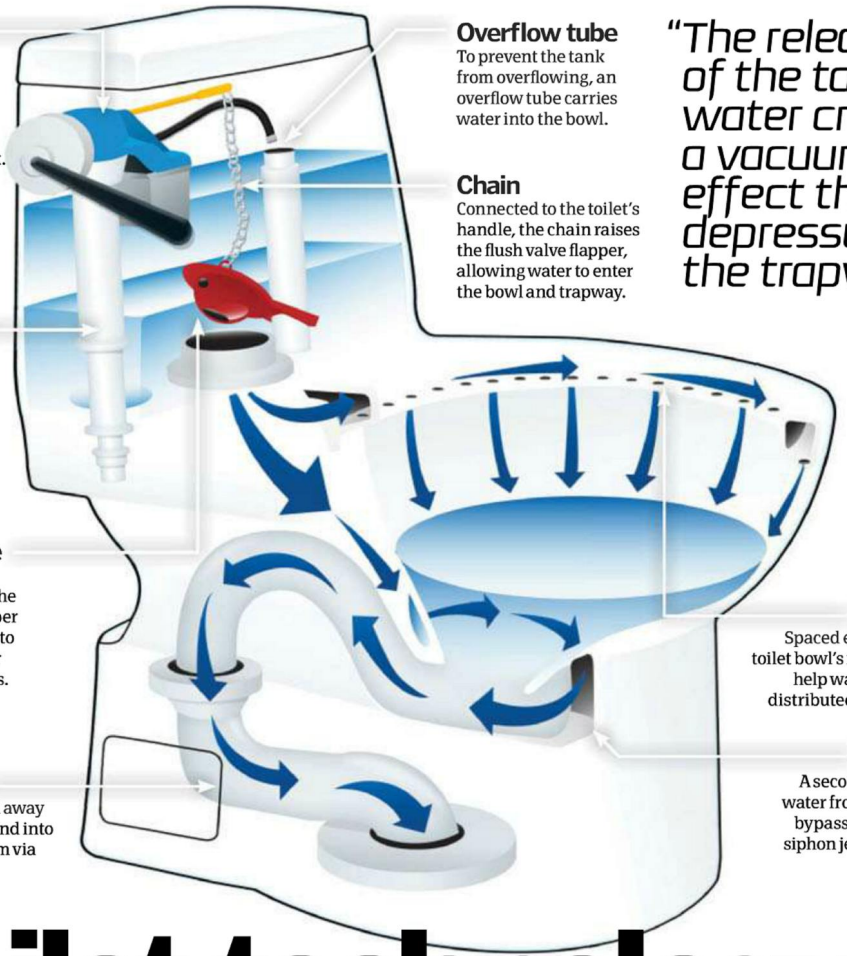
Dunny
2 'Dunny' is the Australian term for an outside toilet. The word derives from the British word 'dunnekin', meaning dung house. The person who empties it is called a dunnyman.

Class
3 The precursor to the modern flush toilet was invented by English courtier John Harington in 1596. However, it didn't enter widespread use for another 300 years.

Duo
4 One of toilet's more recent advances has been the 'duoset' flushing mechanism. The first gives a smaller flush for urine, while the second gives a larger flush for faeces.

Sustain
5 Due to large amounts of water used per person each day on flushing (90 litres/19.8 gallons on average), rules have been introduced to reduce the amount used by toilet systems.

DID YOU KNOW? *The first pay toilet in the United States was installed in Terre Haute, Indiana in 1910*



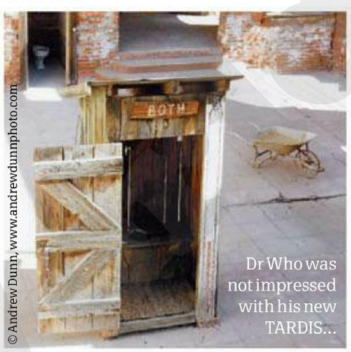
> "The release of the tank's water creates a vacuum effect that depressurises the trapway"

Toilet technology explained

Ever wonder about water closets? Here are the facts about flushing...

Modern flush toilets work in two main stages. First, in order to empty waste from the bowl, a complex flush mechanism is activated. This section is contained within the toilet's tank – the part of the toilet positioned above the bowl – and is initiated when a user presses the toilet's handle. Once pushed, the handle pulls up a chain connected to a flush valve – a rubber stopper that acts as a gateway to the bowl, siphon and trapway. The water in the tank, which has been filled via a filler tube from the mains supply, then exits the tank and descends into the bowl. It follows a rim shelf perforated with equidistant holes, as well as a smaller secondary passage directly into the toilet's siphon – the kinked pipe that sits between the trapway and the bowl. The release of the tank's water occurs in roughly three seconds, which creates a vacuum effect that depressurises the trapway, generating a large suction force that drags the contents of the bowl down into the sewerage system.

Once flushed, the toilet's tank needs to refill itself for further use. First, now the tank is devoid of water, the flush valve falls back down onto the gateway to the bowl. This reseals the tank. Next, the tank filler valve is switched on either electronically or by a traditional ball cock (a float mechanism that pivots on an axle to open the filler valve when the water falls). This allows water to re-enter the tank through the filler tube, filling it to a preset level, as well as down the overflow tube to refill the bowl. The filler valve is then shut once more, either by the rising of the float or by another control system. Finally, the refilling of the tank re-pressurises the siphon and trapway, blocking any gasses and waste from re-entering the system. It re-creates a large water surface area in the main bowl, ready for reuse.



© Andrew Dunn, www.andrewdunnphoto.com
Dr Who was not impressed with his new TARDIS...

War of the water closets

For years, a secret war has been raging over the proper way to hang toilet paper...

In 1989, a survey of American habits discovered that 68 per cent of people questioned staunchly preferred the 'over' toilet paper orientation. They cited that it is easier to grab, allows the design to be clearly seen and is more hygienic, as there is less chance the user will brush their dirty hands against the WC's wall while reaching for it. Advocates of the 'under' orientation cited it grants a tidier appearance, unrolls less easily by accident and is harder for a pet or child to tamper with.

US comedian Jay Leno and advice columnist Ann Landers have had their say. Leno states that, "if people don't have it right [over], they obviously don't know which way it's supposed to go," while Landers writes, "The toilet paper needs to be hung down along the wall."


OVER?


OR UNDER?

2x © Elya

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"Memory foam was designed with aircraft seat safety and protecting astronauts in mind"



Espresso machine teardown

Take a look at the core components of a mid-range home espresso machine



Water tank
This is a simple storage area for unpressurised water, which is filled manually by the user prior to operation.

Pressure pump
As with most espresso machines, water is drawn from the tank by a pump. This is ensured by a pressure differential between the pump core and water tank.

Boiler
Consists of a housing shell (to hold water), a heating coil (to bring water from the tank up to optimal temperature) and dual thermal sensors to monitor steam and water temperature.

Portafilter
Unlike pro-grade espresso machines, the Barista machine uses a pressurised portafilter rather than a commercial one. This ensures that consistent pressure is generated automatically – regardless of coffee grind and tamp level – creating consistently decent espressos for the amateur user.

Steamer
As well as heating up water for pressurised filtering through coffee, the machine's boiler also generates steam for heating/frothing milk. This facility is accessed and controlled through the steam wand.

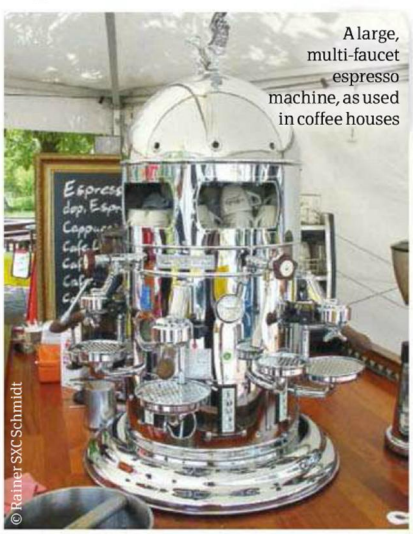
Espresso machines

The science and technology behind a silky smooth espresso

Espresso is a brewing method for coffee that, through the filtering of ground coffee through highly pressurised water, generates an intense, deep and syrupy caffeinated beverage. Standard filter coffee is brewed using a drip method – heated water is simply poured over coffee grinds and allowed to filter through them under gravity alone, absorbing their oils and essences. However, espresso is a considerably more complex brewing method that involves many stages of preparation and production. These variables, which can have a dramatic impact on the finished product, include water temperature, pressure level, filter type, tamp level (how much the ground coffee is compacted before brewing), fineness of the bean grind, type of grinder, freshness of the beans and type of bean roast.

For the espresso machine brewing process, the beans, which have been grown and roasted, are first ground into incredibly fine, uniform grains using a grinder. Next the grains are compacted by a tamper (a weighted device used to compress the grains) into the coffee machine's portafilter, a basket device used to control the flow of water filtered through the grains. On home espresso makers, this filter is usually the pressurised variety, which is designed to automatically compensate for poor/uneven grind and tamps. The espresso machine's pump then draws water from its tank into its boiler for heating to the correct temperature. Advanced machines use a 'roller coaster' technique, where the ideal temperature is maintained in a constant process of water heating, temperature checking, boiler disconnection, temperature checking and water reheating. This means that the water temperature constantly fluctuates either side of the ideal, resulting in a faster ideal temperature pick-up time when water is required for an espresso.

Finally, the water is pressurised and forced through the filter and coffee grains. The heat and pressure of the water extracts and emulsifies the essences of the ground coffee, producing a thick, syrupy liquid topped with a layer of crema – a fine-celled foam imbued with the taste and aromatic properties of the bean.



A large, multi-faucet espresso machine, as used in coffee houses

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How does memory foam remember?

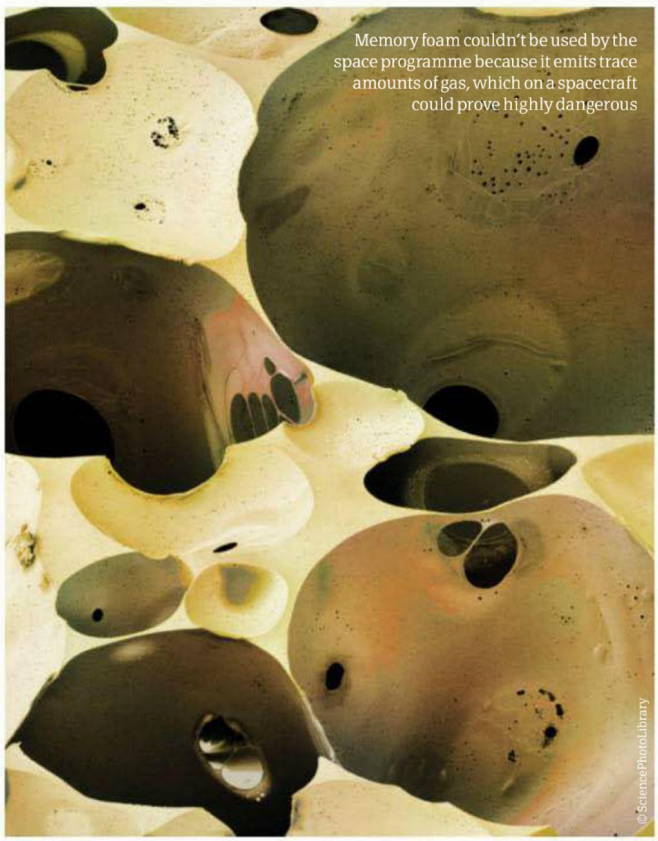
NASA's invention now used to help us get a good night's sleep

One of the most widely used NASA spin-off inventions, memory foam – also known as 'temper foam' – was originally designed with aircraft seat safety and protecting astronauts from g-forces and collisions in mind. This special plastic foam has the ability to deform under extreme pressure, absorbing the energy from crashes and providing shock absorbency while also returning to its original shape.

A foam can be a solid or a liquid that contains trapped bubbles of gas inside it. Memory foam is a solid visco-elastic foam – 'visco' (as in viscous) means that it moves when you apply pressure, and 'elastic' means it returns to its original shape when you remove that pressure. This particular foam is made from open-cell polyurethane, which is a synthetic polymer that features a network of tiny pores or bubbles that shift under pressure, rather than merely compressing. Memory foam responds to changes in temperature and tends to be firmer when it's cool but softer when it's warm. Upon applying pressure, the foam distributes the weight placed on top of it. This material has since been used for many other useful applications, such as mattresses, crash helmets, shoe insoles and even prosthetics.



Memory foam can be depressed to ten per cent of its usual size and still spring back into shape



Memory foam couldn't be used by the space programme because it emits trace amounts of gas, which on a spacecraft could prove highly dangerous

Steam iron anatomy

We break open an everyday household steam iron to see how it keeps your clothes wrinkle free

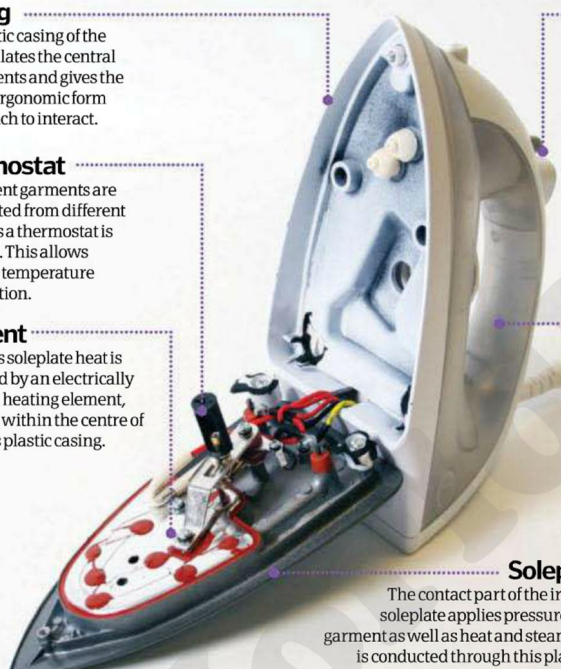


Solid irons were heated via open fires or ovens

Casing
The plastic casing of the iron insulates the central components and gives the user an ergonomic form with which to interact.

Thermostat
As different garments are constructed from different materials a thermostat is installed. This allows soleplate temperature modification.

Element
The iron's soleplate heat is generated by an electrically powered heating element, installed within the centre of the iron's plastic casing.



Features
Aside from seeping steam out through the soleplate, modern steam irons also feature direct water and steam pumps at the fore of the casing, operated manually by pressing these buttons.

Reservoir
In order to produce steam, steam irons need to draw on a reservoir of water contained within the casing. This is topped up manually by the user.

Soleplate
The contact part of the iron, the soleplate applies pressure to the garment as well as heat and steam. Heat is conducted through this plate and steam through a series of perforations.



Ironing out the facts of your everyday steam iron...

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"An ice-cream maker simultaneously freezes your ingredients while churning them together"

Electric ice-cream maker

Inside the machine that transforms a handful of ingredients into the much-loved frozen dessert

An ice-cream maker works by simultaneously freezing your ingredients while churning them together. The ice-cream mixture is placed in a double-walled bowl, which has a coolant sandwiched between its two layers. Some more snazzy devices let you remove and pre-chill this chamber before you start, while older versions use a combination of ice and rock salt, which melts the ice to lower its freezing point.

As the ice-cream ingredients (ie eggs, sugar, cream and flavouring) make contact with the frozen interior of the bowl, the mixture freezes. A set of paddles driven by a motor continually churns the contents to circulate the frozen particles within the mixture. This motion breaks down any ice crystals that form, while introducing air to encourage a creamy texture recognised as 'soft scoop' ice cream. If you hanker after a harder scoop, or you're blending a boozy dessert, you may need to refrigerate your ice cream in order to complete the freezing process.



Making ice cream step by step



How Blu-Tack sticks

Discover why this versatile adhesive is effective in bedrooms and offices alike

The central component of Blu-Tack is a long-chain hydrocarbon polymer, which, because of its chemical structure, tends to be extremely sticky. In fact, these polymers are so sticky that if the polymer was the only ingredient, the substance would stick to everything and couldn't be handled. It would also act like an extremely slow-moving liquid, flowing down the surface it was attached to over a period of weeks.

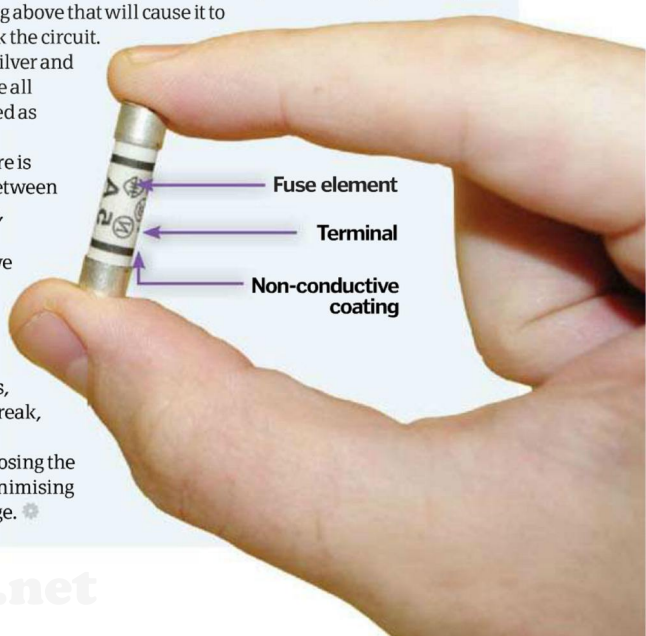
As a result, minerals and mineral oils are both added to the polymer to 'dilute' its adhesive qualities. This enables it to be handled and re-used, ensures that the Blu-Tack will remain where it was stuck, and gives the substance its distinctive colour – added to make sure it isn't mistaken for sweets. Interestingly, despite its success, the precise make-up of Blu-Tack has never been revealed and remains a trade secret.

How do fuses work?

Find out why blowing a fuse is actually a good thing

Fuses are essentially fire breaks, points of deliberate weakness that, if power surges through a house's electrical system, will collapse to prevent damage or fire. This is achieved by the fuse's central component, a strip or strand of metal which has a lower breaking capacity. The metal's breaking capacity is the maximum current that can be passed through it safely, while anything above that will cause it to melt and break the circuit. Zinc, copper, silver and aluminium are all commonly used as fuse wire.

The fuse wire is then placed between two terminals, wrapped in a non-conductive material and then put in place. Then, if a power surge happens, the fuse will break, severing the connection, closing the circuit and minimising further damage.



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5 TOP FACTS
PLUGS AND SOCKETS

Hubbell
1 The invention of the electrical plug is credited to American inventor and industrialist Harvey Hubbell II. Hubbell patented the electrical power plug in 1904.

Landlady
2 Philip F Labre invented the modern American grounded plug when his landlady told him she was getting a small electric shock from plugging her lamp in.

Standards
3 Due to the proliferation of plug/socket/wiring types, technical and safety standards have arisen from country to country. Standardisation of these is being proposed.

Polarisation
4 Polarised plugs only connect to their socket in one orientation, while non-polarised plugs may be connected in two different orientations.

Power
5 The power delivered by a wall socket can be spread across loads with a power strip, a multi-socket adaptor. These are installed with circuit breakers to limit their power.

DID YOU KNOW? *The modern British 'Type G' plug standard was determined in 1947*

Electrical plugs and wall sockets

How your gadgets are connected to the mains safely





Electrical plugs work by providing users with a physical, easy-to-handle plastic connector that acts as a bridge between an electrical appliance's power cable and the mains electrical grid. Plugs come in a variety of shapes and sizes – as do their equivalent sockets – however, all share a couple of basic characteristics and a selection of standardised technology.

Each plug has either two or three separate wired contacts, each of which is contained within a thick insulated cable. These contacts are commonly made from steel or brass (as they are good conductors) and coated with zinc and nickel. The first contact is referred to as the 'line' or 'live' contact, and terminates at the live terminal at the right-hand side of the plug. The live wire carries current from the source (the electricity grid) to the load and vice versa, as the predominating form of electricity delivered to households is alternating current (AC), where the current changes direction up to 60 times per second.

The second wire is referred to as the 'neutral' contact and terminates at the neutral terminal, which is positioned parallel to the live terminal on the left-hand side of the plug. This contact completes the circuit running through the load, in order to generate the necessary power to run it. As with the live contact, current from the source frequently enters and exits the load multiple times per second via the neutral contact. However, unlike the live contact, it remains at the voltage potential of the third wired contact, the 'earth'.

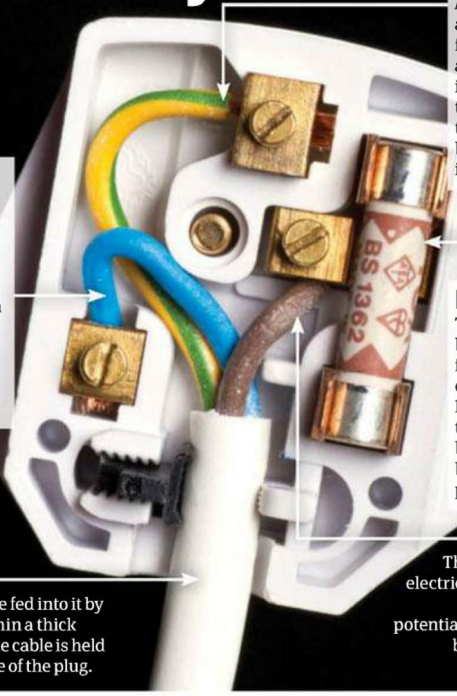
The earth contact is a feature of three-pin plugs, as seen in Britain and Pakistan, and terminates at the earth terminal at the top of the plug. The earth contact is a safety device used to protect against an insulation failure of the live wire (such as the live wire touching the metal casing of an electrical appliance). In practice, this means that if a failure occurs, any potentially dangerous voltage is passed from the electrical system to one or more earthed electrodes, instead of directly into the user.

In some cases, such as in the British 'Type G' plug, a fuse is also present. This is an added safety feature to ensure that excess current doesn't flow through the plug and the appliance. If this were to happen, an electrical fire is almost inevitable. The fuse is located between the live terminal and the live pin, and consists of a cylindrical tube fitted with a tiny, easily melted wire, with contacts at each end. If excess current flows through the fuse, then the wire melts and the circuit is broken.

Plug sockets are designed to partner, in general, a region's chosen plug standard. Certain sockets will accept certain universal plugs, but they may not meet grounding, durability and current capacity safety standards. Sockets, along with certain plugs, can be polarised. Polarisation of sockets and plugs ensures that devices cannot be connected the wrong way round, with the live and neutral pins interchanged. In the majority of products this would not cause an issue, as the circuit would still be complete. However, if live was connected to neutral and vice versa in products such as toasters with exposed metal elements, a different outcome would occur. When the user turned them off, their internal wiring would still remain active, causing an electric shock if tampered with.

Plug anatomy

Understand the basic components of a British 'Type G' plug



Earth
As many electrical appliances are made from metal, the risk of an electric shock is high if a live wire touches their sides. The earth terminal prevents this by transferring current into the ground.

Neutral
The neutral wire completes the circuit running through the load (for example, a television) and, in a properly operating circuit, carries the same voltage potential as the earth wire.

Fuse
The fuse acts as circuit breaker in the case of a fault in the appliance causing excess current. It contains a tiny wire that's easily melted by excess current, breaking the circuit and preventing damage.

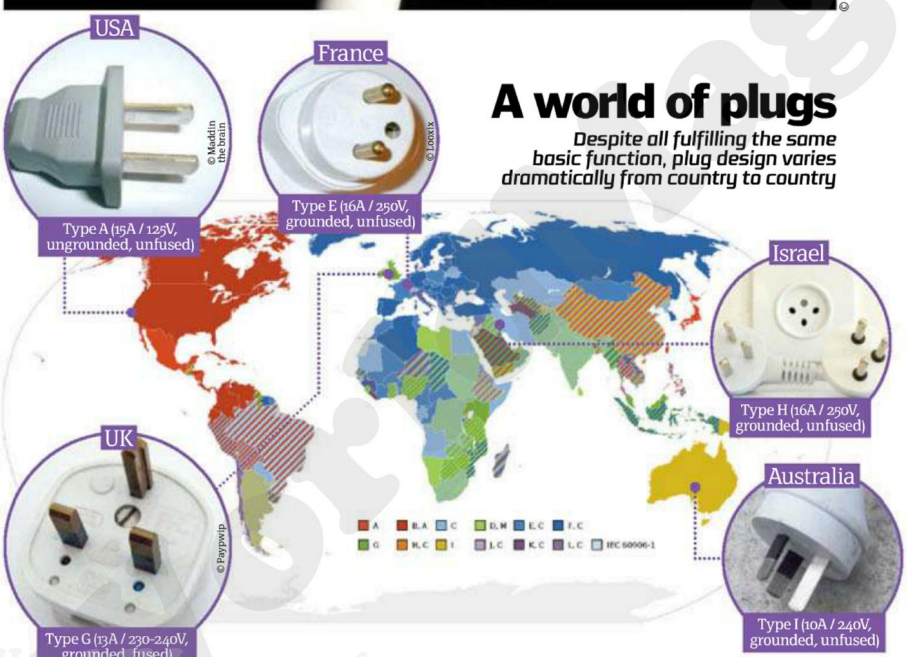
Live
The main entrance point of electricity from the grid, the live wire carries current. The potential of the live contact varies between two positive and negative peaks.

Cable
The plug's wires are fed into it by and contained within a thick insulated cable. The cable is held by a grip at the base of the plug.

© Science Photo Library

A world of plugs

Despite all fulfilling the same basic function, plug design varies dramatically from country to country



"The hot dry air is produced by sucking in cold air that then passes through a heating element"

How do condensing tumble dryers work?

What's the quickest way to dry domestic laundry indoors?

The interior of a clothes dryer consists of a large rotating drum with paddles that lift and separate wet washing as it spins round. This enables the laundry to be efficiently dried by heated air that enters via holes at the back of the drum.

The hot dry air is produced by sucking in cold air that then passes through a heating element. A thermostat sets and regulates the temperature, switching the element on and off to prevent the washing from overheating.

The air exhausted from the drum goes through a filter that traps lint from the dried clothing, and exits through a vent hose. Some tumble dryers send the expelled air through a heat exchanger and condenser to convert it into water that is drained away or collected.

Tumble dryers: the key components



© Bosch

This Bosch model contains technology not included in this article. For full details of Bosch dryers, please visit www.bosch-home.co.uk

Wireless baby monitors

How to hear and watch your baby on your phone or tablet PC with the latest surveillance technology

In their most basic form, baby monitors are just a radio transmitter that uses a fixed frequency usually in the 49.300MHz, 900MHz or 2.4GHz ranges. To reduce interference, some systems also employ digital enhanced cordless telecommunications (DECT) technology, similar to that used in cordless phones, while others can be linked to smartphones or tablet computers.

A modern monitor works by detecting any sound – or movement if a video camera is also being used – and transmitting the audio or video wirelessly to a receiver.

The devices work in a similar way to two-way radios with the addition of a sensor attached to the microphone that triggers the transmission of the audio or video. Baby monitors are usually what is called 'half-duplex'; this allows one monitor to transmit its signal to any number of receivers simultaneously.



Digital baby monitors have mostly replaced their analogue counterparts. Using an iPad or smartphone now means baby surveillance can be done anywhere, eg systems like WiFi Baby utilise the 3G network for super-clear pictures and sound.

What makes Velcro stick?

Discover the small-scale engineering behind this fastener

Velcro comprises two strips of material – one with lots of tiny hooks, and one with lots of thinner loops – that lock when they are pressed together. This mechanism of sticking was inspired by the way tiny hooks on the seeds of burdock, known as burrs, attach to animal fur and human clothing. The hooks and loops in Velcro are commonly made from nylon and polyester with the hooks being more rigid and thicker than the loops. The more hooks and loops that are attached per unit area, the stronger the bond; heavy-duty Velcro contains up to 400 hooks and loops per square inch. In some cases a five-centimetre (two-inch) square piece of Velcro is enough to support a 79-kilogram (175-pound) person.



© SPL

RECORD BREAKERS
BINOCU-SCOPE

8.4m

WORLD'S BIGGEST 'BINOCULARS'

The Large Binocular Telescope (LBT) located on top of Mount Graham in Arizona, USA, employs two 8.4-metre (27.5-foot) mirrors to view the sky. While it might look like a giant pair of binoculars at first glance, it's technically an optical telescope.

DID YOU KNOW? *The idea of binoculars was explored shortly after the telescope was invented in the early-17th century*

Binoculars in focus

Learn about the precise engineering that goes into these instruments in order to bring distant objects up close and in focus

Binoculars work just like a pair of matching telescopes, except they provide a magnified stereoscopic view of faraway objects. Their main advantages over a single lens monocular (telescope) is that they provide depth perception, they are far more comfortable because they allow viewing with both eyes and the visual acuity is better because the brain has two sets of visual data to process.

The basic job of binoculars is to prescribe a folded path for the light entering the objective lens through to the eyepiece, and ultimately the operator's eye, so that the appropriate magnification can be achieved without increasing the overall length of the binoculars.

Each of the lenses has a pair of reflecting prisms inside that re-invert (that is flip and reorient) the image that is received by the lens. The most common type of binoculars incorporate Porro prisms, which are in fact named after their Italian inventor, Ignazio Porro. However, you'll find that roof, or Dach, prisms are being used in some newer models that allow for a straight profile, with the eyepiece in line with the objective lens (as found in the more compact binoculars). They're slightly more comfortable and easier to manage than Porro-prism types, but they do need more careful aligning and lose more light, plus they are generally more pricey than Porro-prism instruments.

Binocular optics are generally described by two figures. For example, the 10 in a 10x42 pair of binoculars refers to the magnification, while the 42 refers to the diameter of the objective lens in millimetres.

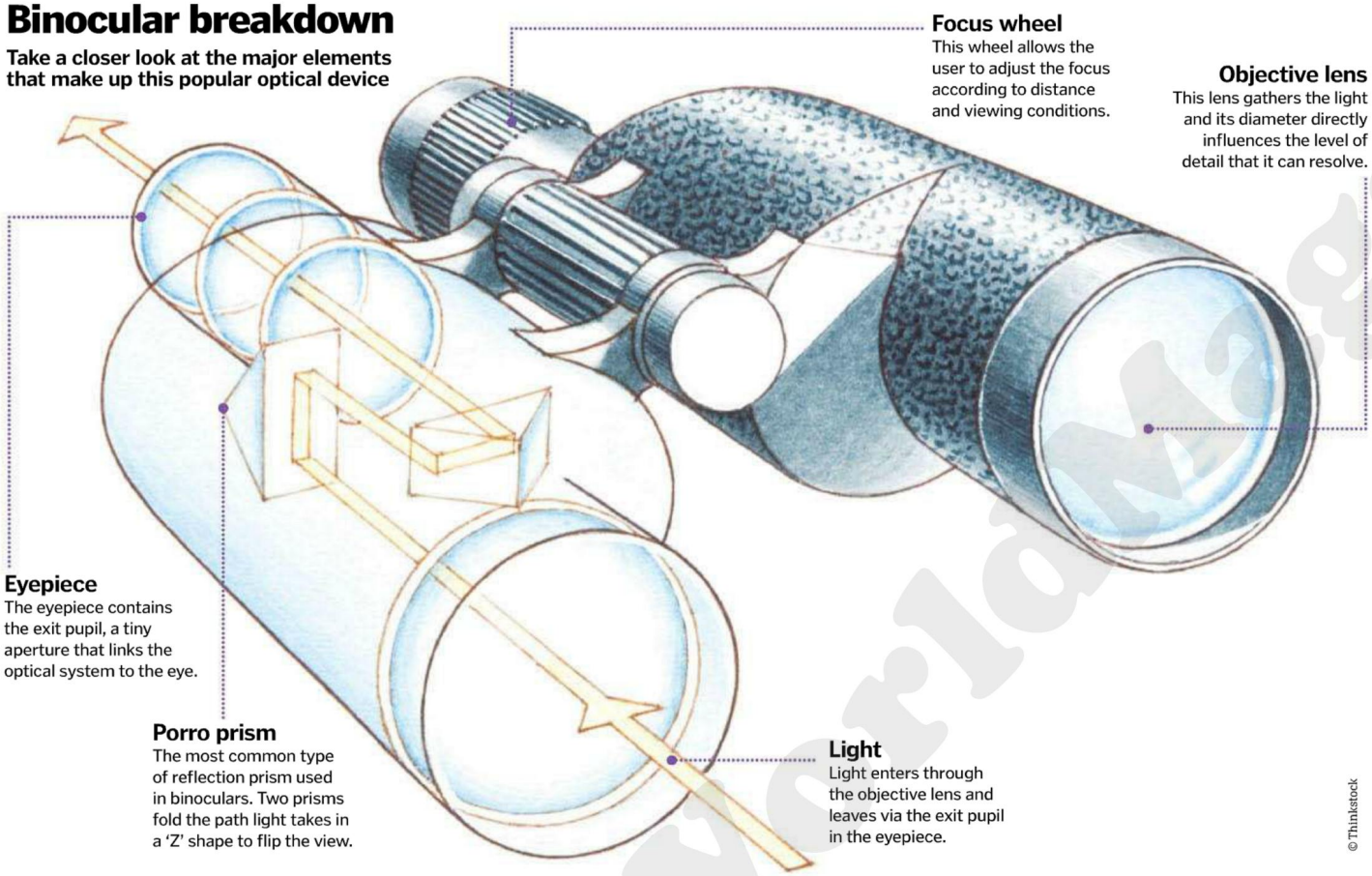
Binocular tech under the microscope

Modern binoculars employ a number of optical technologies in order to improve visual performance. The most common are the different optical coatings: a phase-correction coating on the surface of a roof prism, for instance, is used to compensate for the reduction in contrast and resolution that compact binoculars are known for. Anti-reflective coatings on every optical surface in certain binoculars can improve image contrast, while mirror coatings of aluminium or silver are used in some models of roof-prism binoculars to reduce the amount of light that is lost.

Binoculars which have a high degree of magnification may include some form of image stabilisation too. This is used because even the slightest tremor in the hands can significantly distort the image. These are often powered mechanisms driven by gyroscopes that dampen the effects of small, unintentional movements (see page 34 for more detail), although image-stabilisation technology tends to increase both the weight and price-tag of the binoculars.

Binocular breakdown

Take a closer look at the major elements that make up this popular optical device



Focus wheel
This wheel allows the user to adjust the focus according to distance and viewing conditions.

Objective lens
This lens gathers the light and its diameter directly influences the level of detail that it can resolve.

Eyepiece
The eyepiece contains the exit pupil, a tiny aperture that links the optical system to the eye.

Porro prism
The most common type of reflection prism used in binoculars. Two prisms fold the path light takes in a 'Z' shape to flip the view.

Light
Light enters through the objective lens and leaves via the exit pupil in the eyepiece.

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"Dehumidifiers work on the principle that when damp air is cooled it loses its ability to hold water"

How dehumidifiers work

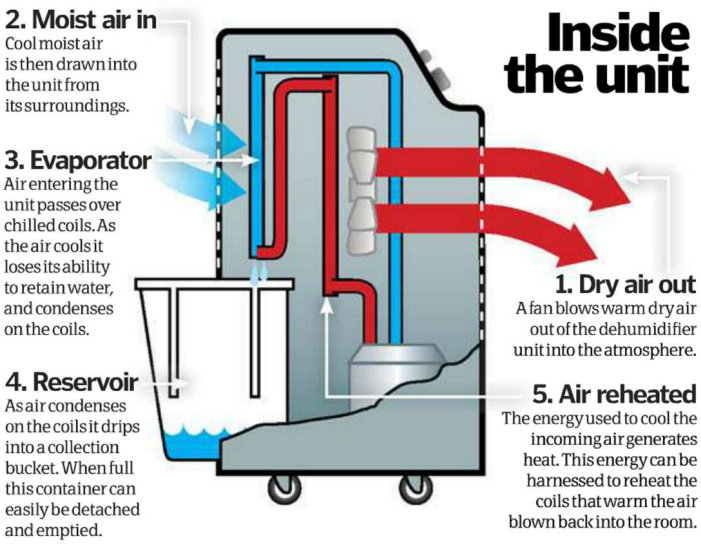
The household appliance that takes water out of the atmosphere

Dehumidifiers are used in order to regulate the level of humidity in an environment by removing excess moisture from the air.

They work on the principle that when damp air is cooled it loses its ability to hold water; the air's moisture converts to liquid form, which can then be collected and tipped away.

There are three major types of dehumidifier that employ differing techniques: compressor (shown in the image); desiccant, which uses a wheel filled with a drying substance (like salt) to soak up water; and peltier, which uses a cold metal plate.





Ionising air purifiers

How do these popular air-cleansing devices ensure a room is kept ultra-fresh?

Ionising purifiers expel ions at a high velocity into their surrounding environment. They achieve this by forcing electrons into a metal needle en masse within the ioniser's casing, causing them to build up at the tip and then be expelled into the surrounding air, attaching themselves to air molecules and becoming ions. This effect produces a cloud of ions in the immediate vicinity of an ioniser, which over time spread outwards through a room.

As these ions collide with other airborne particles – such as smoke, dust or bacteria – they pass on their static charge (usually negative) and force them to become strongly attracted to the closest earthed surface, such as the ioniser's own filter, a wall or carpet. As more and more fine particles are attracted to the ion, they grow in size to the point where they become too heavy to be carried in the air and fall to the nearest surface, allowing them to be collected by a vacuum cleaner or similar device.



An image showing the sterilising effects of an ionising purifier. The petri dish on the top is contaminated with salmonella enteritidis, but when it is deposited in an ioniser, it is purified, as shown on the bottom



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Humidifiers explained

We reveal the technology inside this common household appliance and just how it puts moisture into the air around us

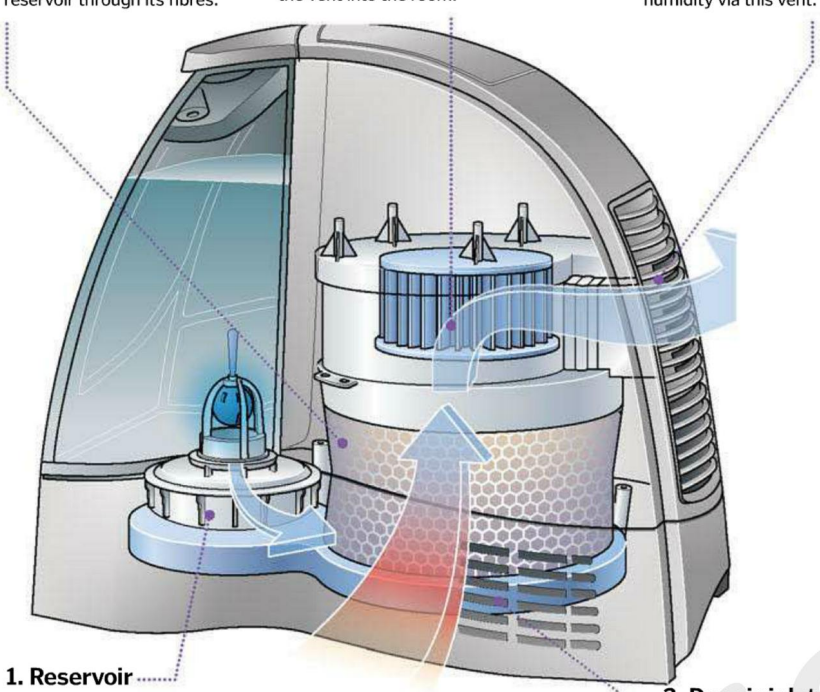
The ideal level of humidity for our homes is around 40-50 per cent in order to feel comfortable. If it is too low, our skin and mucosal membranes can dry out, which can consequently lead to cracks in our skin, as well as more serious breathing difficulties.

For temperate and colder regions of the world, low humidity usually happens during winter when very little moisture exists as vapour in the air. We talk about 'relative humidity', because warmer air can hold more water, and the air will hit saturation point (that is 100 per cent humidity) with considerably less moisture at cooler temperatures.

Humidifiers work by putting water back into the air of a room or an entire house. Using several methods they can pass H_2O from a reservoir up through a filter where a fan blows the vapour into the air. A steam vaporiser boils water to release vapour, an impeller uses a diffuser to break water into droplets and releases it as a fog, while an ultrasonic humidifier vibrates a diaphragm, which also turns water into tiny droplets.

Evaporative humidifier in action

A closer look at how the most common type of domestic humidifier works



3. Wicking filter
A replaceable wicking filter soaks up the water from the reservoir through its fibres.

4. Fan
A fan pushes the humidified air out of the vent into the room.

5. Moist air outlet
Moist air enters the room and raises its level of humidity via this vent.

1. Reservoir
A reservoir of water (sometimes distilled to remove minerals) drains into the filter.

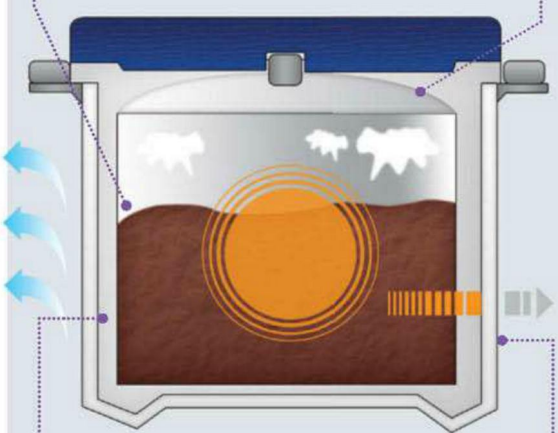
2. Dry air inlet
Dry air moves into the humidifier and across the wicking filter, picking up tiny water droplets.

Inside a slow cooker

Good things come to those who wait, but what are the main components of these cooking devices?

Internal casing
The actual cooking pot is made of a thick ceramic material.

Lid
Lids can also be insulated and are necessary to keep the food from drying out while cooking.



Vacuum cavity
A vacuum in the double-wall cavity keeps the food hot by preventing heat conduction across it.

External casing
A hard outer pot protects the contents and forms the external wall of the cavity.

How slow cookers work

Discover just how this purveyor of tasty stews and comfort foods cooks those delicious meals

The electric slow cooker is based upon a centuries-old concept of heating food slowly and evenly at relatively low temperatures for long periods of time. By sealing it in the pot, the food bastes in its own juices and moisture that it releases, so tough plant and animal fibres are softened.

Electric slow cookers came along in the Seventies and comprise of three main components.

The outer casing is usually made of steel, designed to protect its contents and hold the heating coils between it and the inner pot in place. The inner casing is a ceramic dish that sits on the heating coils and cooks the meal. Between the inner and outer pots is a vacuum-insulated cavity, which stops heat from passing across the inner casing and so keeps the food hot – in the same way a vacuum flask can keep liquids hot for longer than an ordinary flask. Finally, a lid ensures that any moisture is sealed in.

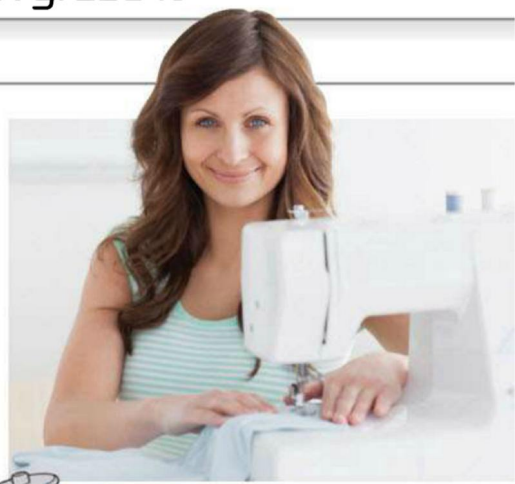
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"The needle drags a loop of thread to the other side of the fabric, where a hook grabs it"

How do sewing machines work?

Ever wondered how a sewing machine can stitch fabric so quickly yet precisely?



The sewing machines that we use these days do the job of a highly skilled tailor in a fraction of the time. Before they were invented in the late-18th century, the fine stitching that we take for granted on our everyday clothes today would have only been available to the wealthiest members of society.

There are several basic methods of stitching that various models employ, but the loop stitch is the most common. This works by passing a needle tied with thread through both pieces of fabric and out the other side, then back again. When stitching manually this involves passing the needle to the other hand and turning it around to go back, which is too elaborate for a machine to perform, and also unnecessary.

Instead a sewing machine uses two parts: a needle and a looping hook. The machine needle passes only partway through the material with the eye at the sharp end rather than the blunt end like its handheld equivalent.

As it's moving through the fabric, the needle drags a loop of thread to the other side, where a hook grabs it and either loops the thread around itself or around a separate piece of thread. The needle then retracts and the thread is drawn tight, fastening the fabric together.

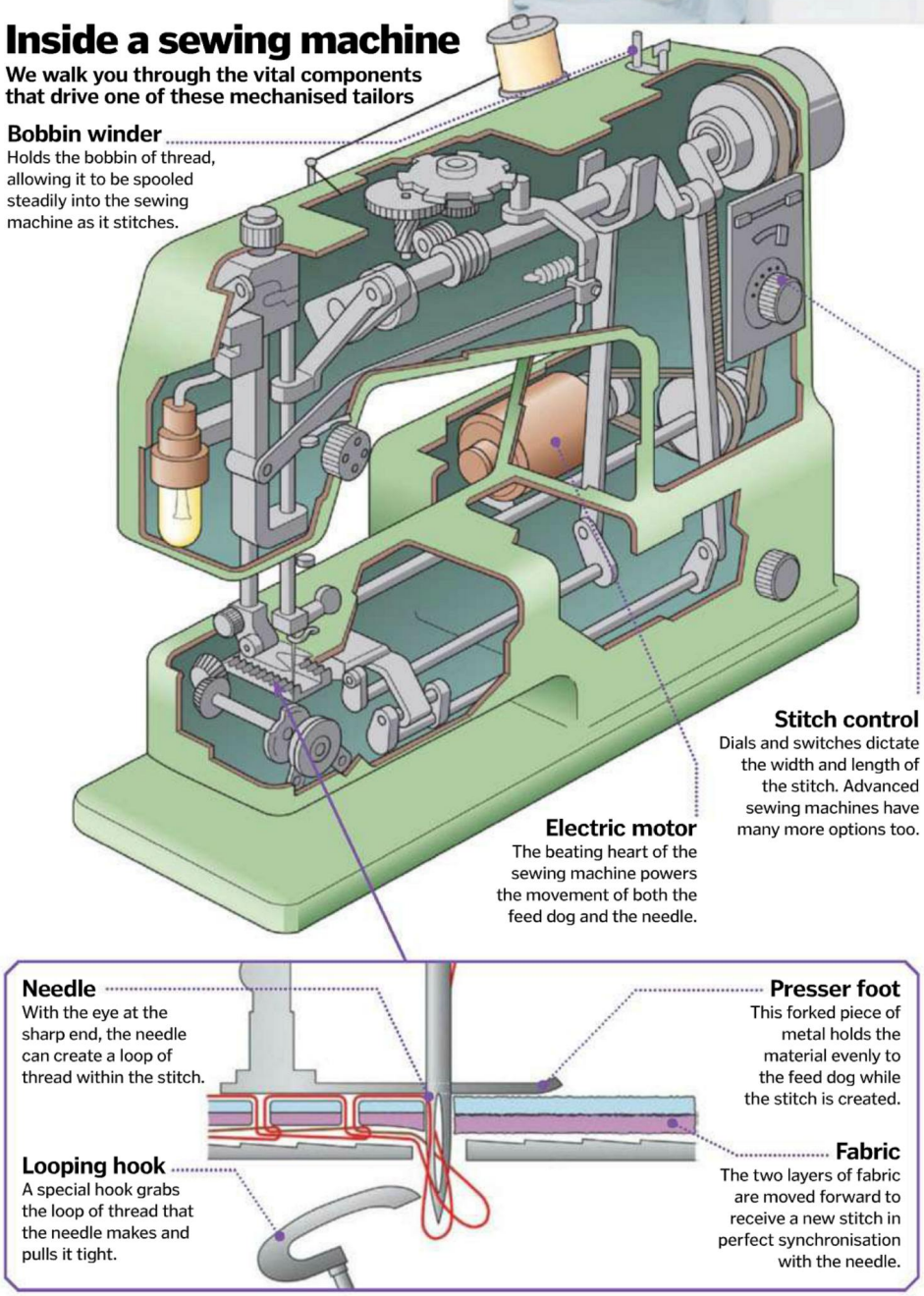
Just what exactly is the feed dog?

Inside an electric sewing machine is a sophisticated series of gears and shafts that all connect to a single motor. One part of the motor controls a crank that pulls the needle bar up and down, plus a thread-tightening arm, which creates a slack loop and then tightens it to form the stitch. The other vital part of the sewing machine that the motor controls is the feed dog. This is the belt that steadily and evenly moves the fabric forward in synchronisation with the needle to create a new stitch.

The feed dog is pressed up against the fabric where it rolls forward, shifting the material a short, consistent distance before dropping down again to release it. The entire process of feed dog, needle bar and thread-tightening arm is entirely driven by the motor, which in turn is controlled by a pressure-sensitive footplate operated by the user.

Inside a sewing machine

We walk you through the vital components that drive one of these mechanised tailors



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Singer sewing machine

One of the earliest and most celebrated sewing machines, the Singer set the benchmark of fabric processing for generations

The Singer sewing machine – while not actually the first to be invented – is considered the device that propelled this industrious invention into the mainstream. The reason for this was the addition of small design tweaks that improved usability and efficiency considerably over previous models. These consisted of a circular feed wheel below the cloth plate, a thread controller and the use of gear wheels, to transmit power from the hand wheel to the machine's vertical needle and the shuttle. The Singer was also the machine to introduce foot power in place of the hand-driven crank wheel, leaving the operator's hands free (as is common today).

Despite Singer having to pay royalties to sewing machine patent holder Elias Howe, these benefits quickly led to the machine becoming market leader. Sales jumped from 810 units sold in 1853, to 262,316 units sold in 1876. Further, Singer laid the groundwork for its current dominance of the sewing machine market, opening factories in England, Paris and Brazil.




© Kriss Szkurlatowski

Getting corks into bottles

Discover how cork plugs are inserted into wine bottles

Corks are inserted into wine bottles using a specially designed mechanical corking press. These range from small handheld presses, which are operated manually, through to giant automated presses that can cork hundreds of bottles at once. Regardless of size and method, however, the principle factor to the success of the press is the natural elastic properties of cork.

Cork is harvested from the bark of the quercus suber tree, which is primarily cultivated in Spain and Portugal. The cork – which contains high levels of the waxy substance suberin – is acquired by stripping the bark of the tree, which over time (nine to twelve years) generates a spongy cork cambium tissue. This bark, once processed, retains the spongy, elastic properties held by the cambium and waxy properties of the suberin, allowing it to be compressed under pressure.

Mechanical hand presses operate by placing the cork within a central cylindrical vice chamber, which is then aligned with the bottle's mouth. Acting like a pair of pliers, the press then squeezes the cork so that it matches the circumference of the bottle's neck, and then pushes it downwards in a lever action.

Corking a bottle



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How door handles work

We let you in on the technology behind the device that we just couldn't leave the house without using

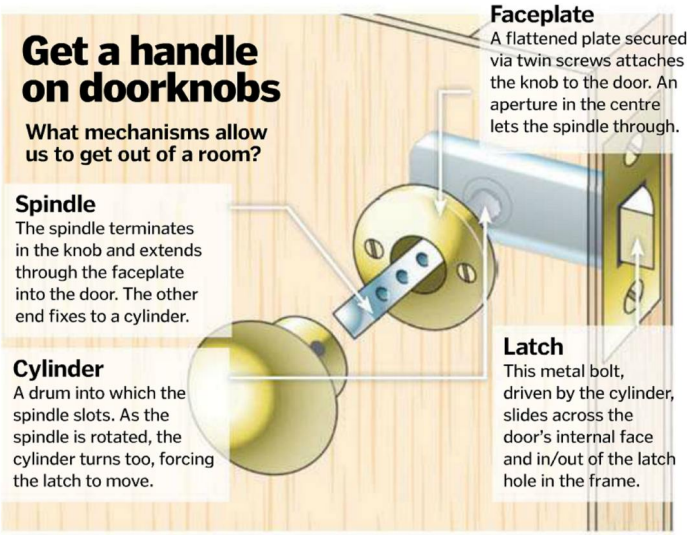
A door handle controls a door by manipulation of a latch – a mechanical fastener that joins two or more objects together. In this case, a latch connects the door with its frame and tends to embody a sliding bolt installed in the door and a receptacle in the frame.

The latch's position is determined by the handle – which can take many forms including knob and lever. This is connected to the latch via a spindle and cylinder. When the handle is pulled or rotated (depending on the type of handle used), the action is carried by the spindle into the cylinder, which turns clockwise or anti-clockwise depending on its orientation.

The movement of the cylinder causes the attached bolt to be forced across the door's internal face, sliding in/out of the frame's latch receptacle allowing the door to be either opened or shut.

Get a handle on doorknobs

What mechanisms allow us to get out of a room?



Faceplate
A flattened plate secured via twin screws attaches the knob to the door. An aperture in the centre lets the spindle through.

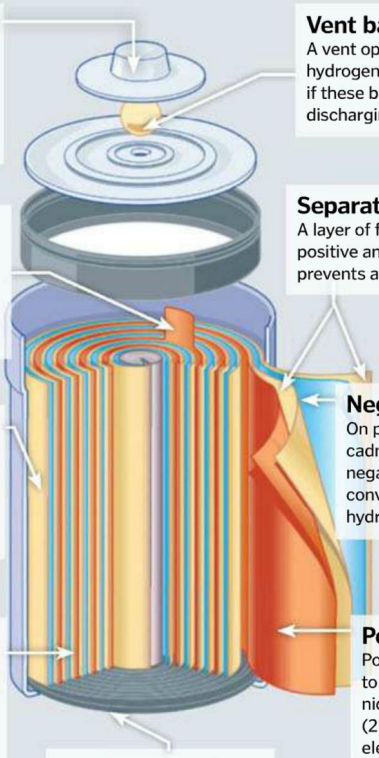
Spindle
The spindle terminates in the knob and extends through the faceplate into the door. The other end fixes to a cylinder.

Cylinder
A drum into which the spindle slots. As the spindle is rotated, the cylinder turns too, forcing the latch to move.

Latch
This metal bolt, driven by the cylinder, slides across the door's internal face and in/out of the latch hole in the frame.

Rechargeable cells

How do nickel-cadmium batteries keep portable devices going and going?



Positive terminal
Power discharges when a device creates a circuit that lets electrons flow from the negative to the positive terminal.

Vent ball
A vent opens to release hydrogen or oxygen gas if these build up during discharging and recharging.

Positive tab
Electrons move from the positive terminal to the positive electrode during power discharge, or vice versa during recharging.

Separator
A layer of fabric in between the positive and negative electrodes prevents a short circuit.

Electrolyte
Electrical charge is conducted to and from the positive and negative electrodes via a potassium hydroxide (KOH) solution.

Negative electrode
On powering a device, cadmium (Cd) in the negative electrode is converted to cadmium hydroxide ($Cd[OH]_2$).

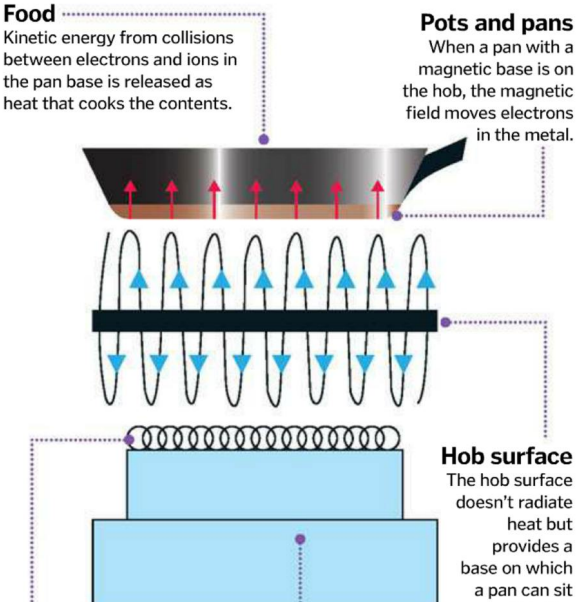
Jelly roll
The positive and negative electrodes, with a separator in between, are wound into a cylindrical spiral inside the battery.

Positive electrode
Powering devices leads to the conversion of nickel hydroxide (2NiOOH) in the positive electrode to $2Ni(OH)_2$.

Insulating washer
The negative terminal of the battery is insulated from the electrochemical processes by a thin film.

How induction hobs heat food

The secret of the hotplate that isn't hot to the touch



Food
Kinetic energy from collisions between electrons and ions in the pan base is released as heat that cooks the contents.

Pots and pans
When a pan with a magnetic base is on the hob, the magnetic field moves electrons in the metal.

Hob surface
The hob surface doesn't radiate heat but provides a base on which a pan can sit within the magnetic field.

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Induction coil
Current passing through the copper wire generates an alternating magnetic field at the surface of the hob.

Power supply
Electrical current is supplied through a stream of electrons to a coil of copper wire under the hob.

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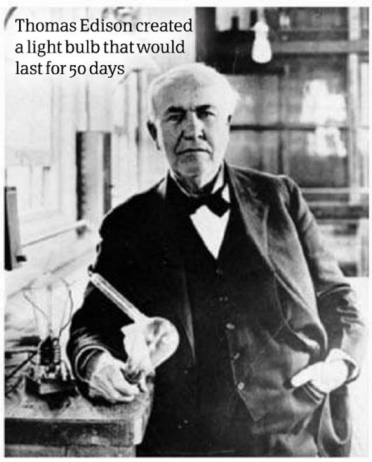
1. Fluorescent
When stimulated by electricity, mercury atoms inside the tube release UV photons. This stimulates the phosphor coating and emits visible light.



2. CFL bulbs
The compact fluorescent light (CFL) bulb works like the fluorescent tube, but is less bulky and can generally be used in the same fittings as incandescent lamps.



3. LED lighting
Diodes in LED lighting are a type of semiconductor. When electricity is applied they emit photons of light. They're more efficient, but more expensive.


Thomas Edison created a light bulb that would last for 50 days

Incandescent lamps

Illuminating the world with electrical light

The incandescent filament lamp (usually known as the incandescent light bulb) produces light by passing electricity through a conducting filament, which excites the molecules in the filament and makes it so hot that it gives out light.

As early as 1802, inventor Humphrey Davy passed an electrical current through a platinum filament to create a brief light. This principle was developed throughout the 19th Century, and by 1878, Joseph Swan was using carbonised thread filaments fitted to platinum leads inside a sealed glass bulb. Thomas Edison used Swan's ideas for the basis of his own lamp bulbs, and in 1880 Edison produced a bulb that would last 1,200 hours using a carbonised bamboo filament.

Further refinements followed, the main one being the production and use of fine tungsten wire as a filament in 1909. This wire can stand temperatures up to 3,382°C (6,120°F) before melting, and allowed for greater light output. Ten years later, it was found that coiling the filament and filling the glass bulb with inert gasses such as argon, neon or nitrogen prolonged the life span of the bulb.

The main disadvantage of incandescent bulbs is that they are not very energy efficient, and can also present a fire hazard if near flammable material.

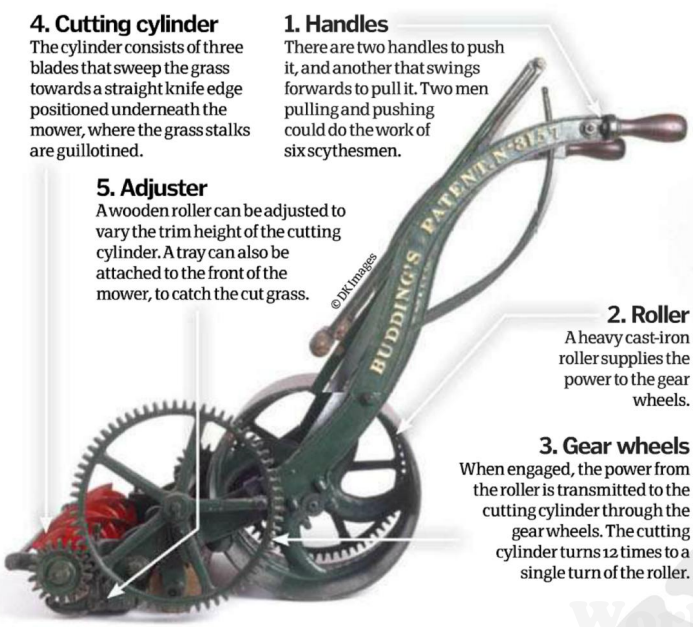
First mechanical lawnmower

Discover how grass was trimmed in the 19th century

The first lawnmowers were intended for use on country estates and pleasure gardens, where grass was kept trim either by grazing animals or by gangs of labourers (mowers) who used long-bladed scythes.

Edwin Beard Budding of Stroud, Gloucestershire, invented the mechanical lawnmower after seeing a carding machine in operation at a local cloth mill. This employed a bladed cylinder that trimmed the nap (fuzz) on woollen cloth. He simply applied the same principle to trimming grass.

Budding's lawnmower consisted of a large roller that, through gear wheels, pushed a cutting cylinder that cuts the grass. With John Ferrabe, who owned the Phoenix Iron Works, he patented it in 1830 and built several wrought-iron and cast-iron prototypes. In 1832, J R and A Ransomes of Ipswich made a viable version under licence from Budding. By 1840, they had sold 1,000 mowers.



4. Cutting cylinder
The cylinder consists of three blades that sweep the grass towards a straight knife edge positioned underneath the mower, where the grass stalks are guillotined.

1. Handles
There are two handles to push it, and another that swings forwards to pull it. Two men pulling and pushing could do the work of six scythesmen.

5. Adjuster
A wooden roller can be adjusted to vary the trim height of the cutting cylinder. A tray can also be attached to the front of the mower, to catch the cut grass.

2. Roller
A heavy cast-iron roller supplies the power to the gear wheels.

3. Gear wheels
When engaged, the power from the roller is transmitted to the cutting cylinder through the gear wheels. The cutting cylinder turns 12 times to a single turn of the roller.

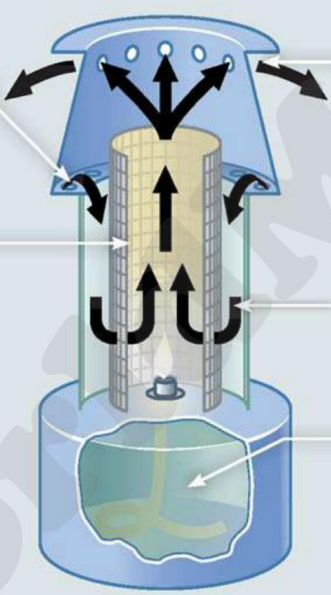
What's inside a Davy lamp?

The safest way to light a 19th-century mine

In the past, tallow candles were used in mines, which were lethal when they encountered certain gases. Sir Humphry Davy, however, invented a lamp in 1815 to deal with the danger of flammable methane gas in coal mines.

Davy's solution was to protect and cool the flame with a gauze shield. When dangerous gas is present, any explosion is contained inside the gauze. If the flame changes its shape or turns blue, it indicates the presence of potentially lethal gases, and if it goes out or splutters, it indicates the presence of carbon dioxide or low levels of oxygen.

Early versions of the lamp were fragile and not an adequate protection against mine explosions until the 1890s.



Air inlet
Air and other gases flow in to keep the flame burning.

Gauze
The iron or copper mesh has to be fine enough to allow in air, but dense enough to arrest any ignition of gases in the atmosphere. It also cools and retains the heat radiating from the lamp flame.

Gas outlet
Gas from the flame safely emerges from this outlet at the top of the lamp bonnet.

Glass
Allows light out of the lamp and provides some protection to the gauze that can easily be damaged or be rendered ineffective due to rusting.

Oil reservoir
The reservoir is filled with oil or naphtha (lighter fluid) to fuel the wick. It is often fitted with a magnetic lock to prevent accidental spillage.

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"Completed in 1092, Su Sung's Cosmic Engine revolutionised astronomical clock design"

How do astronomical clocks keep time?

How did these ancient timekeeping instruments work?

Astronomical clocks are timekeeping devices in the traditional sense. They were first used to calculate the position of the Moon, Sun and the stars in Ancient Greece, around the 2nd Century BCE. The Middle Ages saw the popularity of clocks grow greatly and this included those that timed zodiacal events using crude mechanical techniques. In fact, they often required a much simpler (yet more reliable) sundial to readjust their timings.

Originally these clocks had no dials and simply struck at one-hour intervals, indicating the passing of time via the medium of sound. A 24-hour dial was later added for the convenience of the timekeeper, followed by a Sun clock that charted the position of the Sun across the sky. A Moon plate followed this, which worked in the same way but moved more slowly across the dial until it coincided with the Sun once again, 29 and a half days later, indicating a new Moon.

The astronomical clock was then given 12 zodiac signs through which the Sun passed over the course of the year, though during a leap year the clock was usually stopped for a day to avoid timing problems in the future.

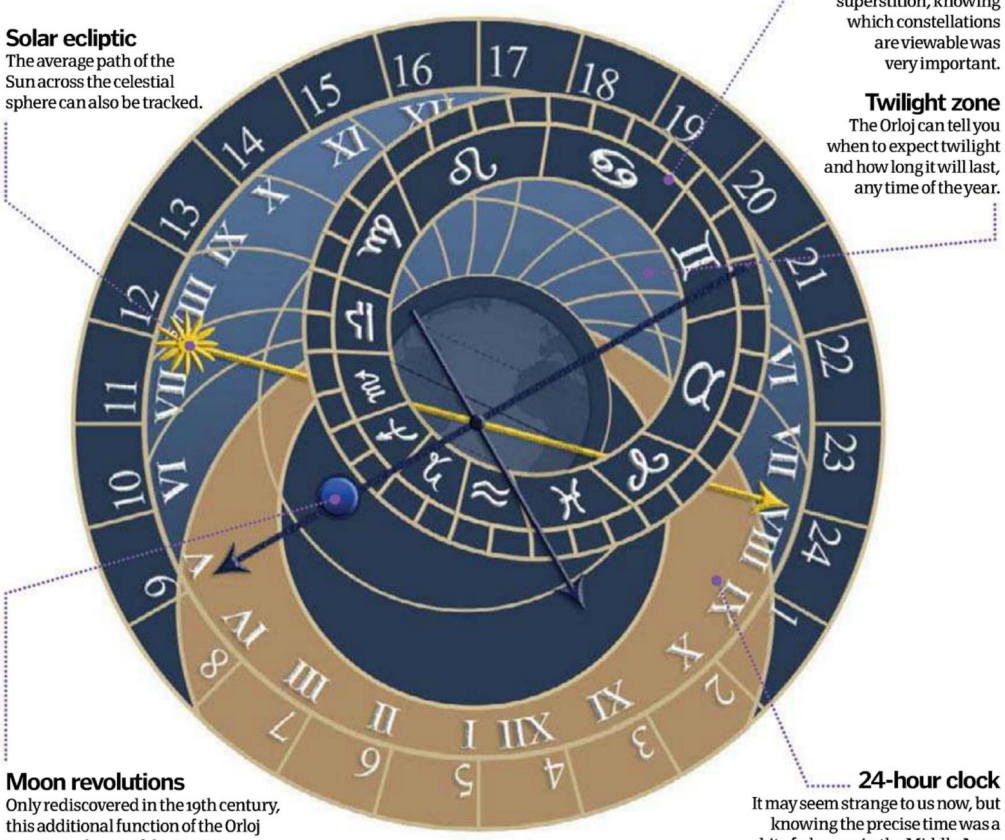
An instrument for measuring celestial bodies, called an astrolabe, could also be added to chart the position of the zodiac signs throughout the year. This was useful as winter signs (eg Capricorn) spend less time visible above the horizon than summer signs (eg Gemini).

Interest in astronomical clocks saw a resurgence in the mid- to late-17th Century as astronomy became en vogue in the wake of Galileo's major influence on the scientific community. These clocks were used frequently right up to the 19th Century, with religion playing a key role in their design. They were particularly popular in Islamic countries, where an astrolabe could be used to calculate the regular prayer times.



After Su Sung's enemies destroyed it, only blueprints of his Cosmic Engine clock were left

How the Orloj measures time



The Orloj

The third-oldest astronomical clock in the world and oldest working example is the Orloj in Prague, Czech Republic. Installed in the southern wall of the Old Town Square in 1410, the oldest parts of the Orloj clock are over 600 years old, although it's been repaired numerous times over the centuries, especially at the end of WWII.

Early astronomical clocks, like Su Sung's 11th-Century Cosmic Engine, were regulated by a wheel turned by falling water, but later examples – including the Prague Orloj – were also reliant on Earth's gravity for movement, via the action of weights, pulleys and levers. The Orloj's design has been improved a number of times over the generations.

The many facets of the Orloj give it 20 different functions in addition to simply telling the time, including keeping track of the tropics, measuring ancient Czech time and monitoring solar and lunar movements.



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5 TOP FACTS
CUCKOO CLOCKS

Prince
1 The first known description of a modern cuckoo clock comes from a 17th-Century German nobleman, who wrote of Prince Elector August von Sachsen owning one.

Black Forest
2 Cuckoo clocks popularity grew during the 18th Century, with Germany's Black Forest at the heart of production. Today they are highly prized and can cost thousands of pounds.

Chalet
3 Through the 20th Century cuckoo clocks were commonly built in the shape of a wooden chalet, a style that originated in Switzerland towards the end of the 1800s, where they were sold as souvenirs.

Minimalist
4 Today, cuckoo clock design has become more varied both in form and function, with traditional and chalet, along with more minimalist and modern, timepieces all available.

Totally cuckoo
5 The world's most extensive and finest collection of cuckoo clocks (with both old and new models) is at the Cuckooland Museum in Cheshire, England.

DID YOU KNOW? *The creation of the cuckoo clock is credited to Ancient Greek mathematician Ctesibius*

Cuckoo clocks explained

How do these bird-ejecting timepieces work?

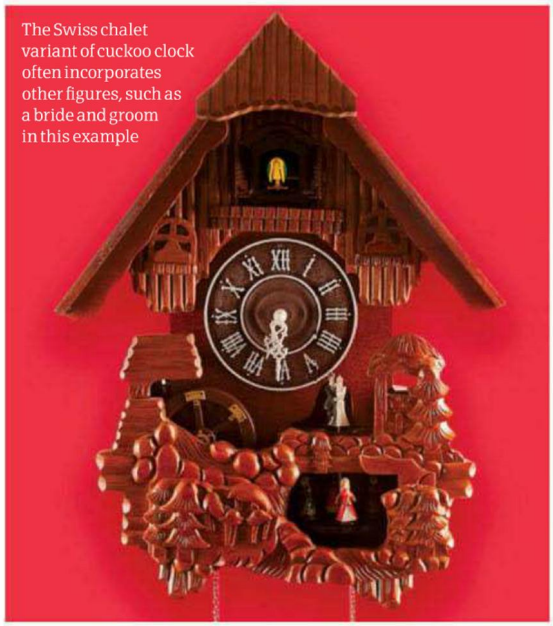
A cuckoo clock is a specialised type of pendulum-regulated (traditionally) timepiece that, as well as striking the hour like a normal clock, releases a small model cuckoo and its audible call too. The clock works through a series of internal and external components that, together, eject the cuckoo and play its call in time with the faceplate's hands.

The cuckoo clock was invented in its 'modern' form during the 16th Century in Germany, and since has diversified into three main types: Black Forest, Swiss chalet and modern quartz.

The first type is considered both the most traditional – it was in the Black Forest area that the first modern cuckoo clocks were created – and most valuable, as all cuckoo clock manufacture in the region is quality controlled. These clocks have full mechanical movements, requiring them to be frequently wound, and are driven by weights that hang down beneath the clock. These movements come in two distinct types: one-day and eight-day.

The second type is the chalet cuckoo clock, which was invented in the late-19th Century in Switzerland. These clocks resemble wooden chalets and use either mechanical or quartz movements depending on their quality. A quartz movement differs markedly from a mechanical one in that it is powered by batteries rather than by winding and weights. The quartz movement works by using an electronic oscillator that is regulated by a quartz crystal to keep time, the oscillator creating a signal with a very precise frequency. Chalet cuckoo clocks also differ from Black Forest varieties in that they commonly have extra moving model features in addition to the traditional bird, such as woodcutter and housemaid figures.

The newest variant of cuckoo clock is the modern quartz. These tend to be more pared back in design and feature non-traditional internal mechanisms – for example, modern quartz cuckoo clocks produce their birdsong electronically via a digital recording, rather than the traditional dual bellows array.



The Swiss chalet variant of cuckoo clock often incorporates other figures, such as a bride and groom in this example

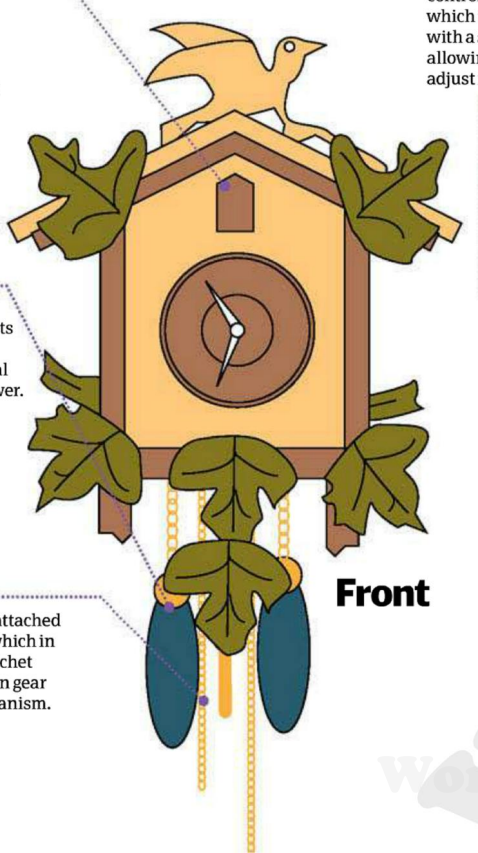
Inside a cuckoo clock

Breaking down a cuckoo clock to see what makes it tick

Releases
Both the front-top cuckoo door and the rear panel are opened by two release tabs, the former automatically when in operation.

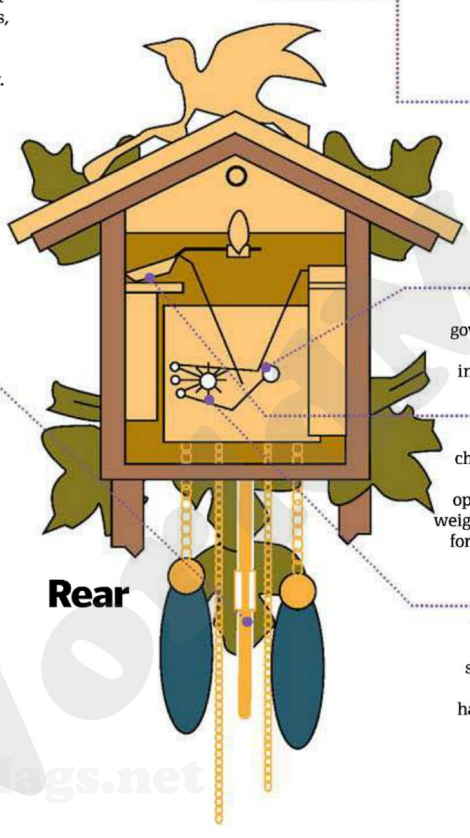
Weights
Usually shaped like pinecones, the weights are made of cast iron and supply the central mechanism with power.

Chains
Each clock weight is attached to a winding chain, which in turn passes over a ratchet wheel, a one-direction gear attached to the mechanism.



Front

Pendulum
The clock's pendulum controls the speed at which the clock runs, with a slideable bob allowing the user to adjust it accordingly.



Rear

Bird
The cuckoo itself is ejected from the clock with a scissor armature, which is controlled by the central mechanism.

Hammer
The clock's hammer is governed by the central gear mechanism, striking an internal gong on each hour.

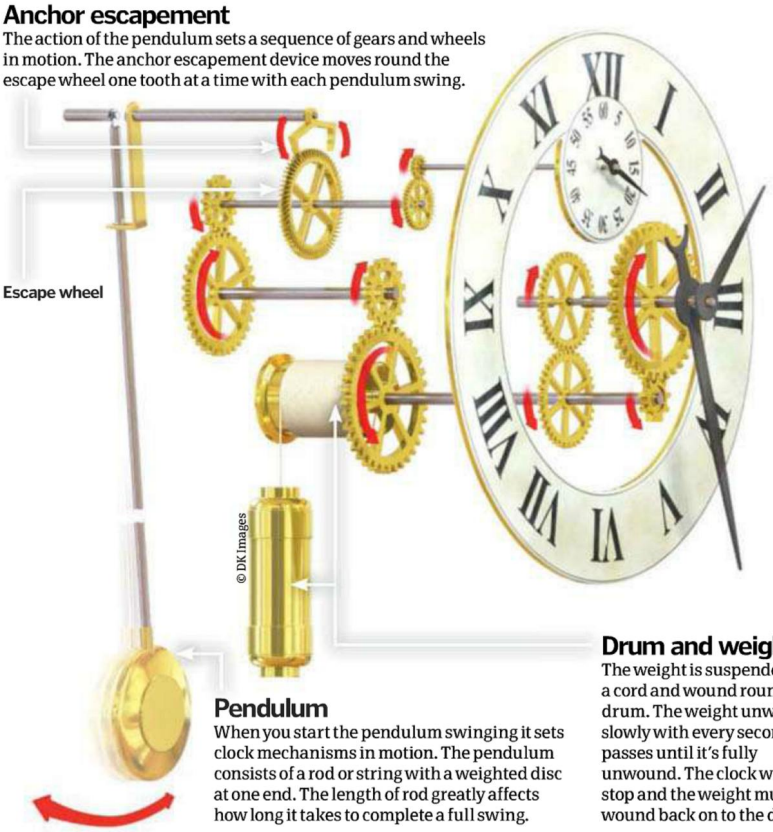
Whistles
The bird's distinctive chirping is created by a pair of whistles. Each whistle operates by dropping a steel weight onto some bellows that forces air to pass over a reed.

Mechanism
The heart of the clock, the mechanism consists of a series of gears that powers the clock's gong-striking hammer, whistle operation as well as bird ejection.

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"When you start a pendulum swinging, it continues to swing due to the forces acting on it"

Anchor escapement
The action of the pendulum sets a sequence of gears and wheels in motion. The anchor escapement device moves round the escape wheel one tooth at a time with each pendulum swing.



Pendulum
When you start the pendulum swinging it sets clock mechanisms in motion. The pendulum consists of a rod or string with a weighted disc at one end. The length of rod greatly affects how long it takes to complete a full swing.

Drum and weight
The weight is suspended from a cord and wound round the drum. The weight unwinds slowly with every second that passes until it's fully unwound. The clock will then stop and the weight must be wound back on to the drum.

Mechanical pendulum clocks explained

How can a swinging mechanism accurately keep the time?

Galileo discovered that as long as a pendulum stays the same length and keeps swinging, the time it takes to swing back and forth is always the same. This makes a pendulum the ideal timekeeper.

When you start a pendulum swinging, it continues to swing back and forth because the forces acting on it aren't balanced. If you swing the pendulum one way, its weight, gravity and the tension in the string pull the pendulum back down towards the centre. However, as the pendulum swings back, its weight and velocity send it swinging back up the other way past the centre point. As long as there is an energy source, the pendulum will keep swinging with this precision indefinitely.

So from where does a pendulum get its power? Well, a weight is suspended from a drum that is attached to a series of gears. As the weight falls it turns the gears that each drive the different clock hands – ie, the second, minute and hour hands.

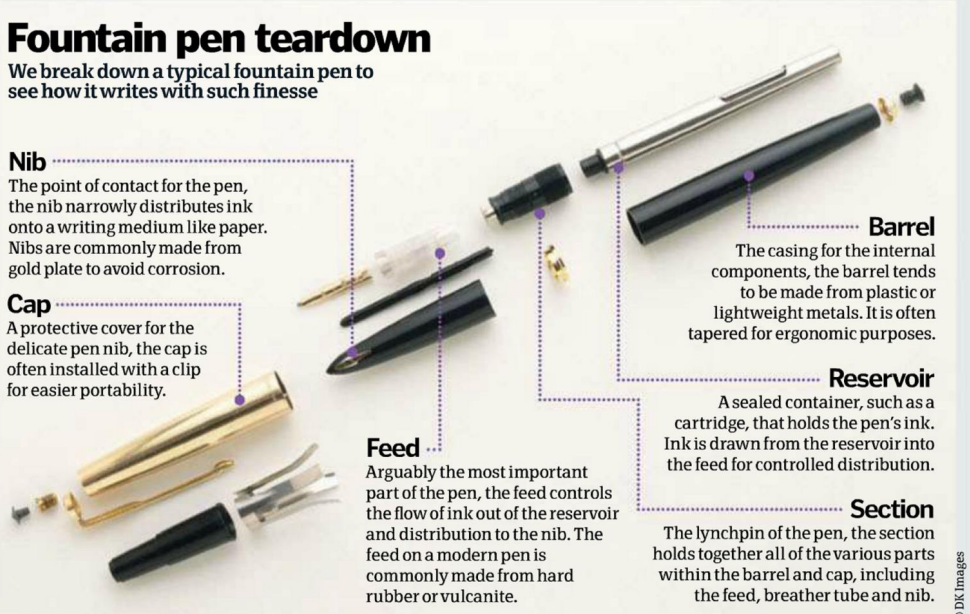
To control the speed at which the gears turn, however, a special escapement device allows each swing of the pendulum to release just one tooth of the gear at a time, giving the pendulum enough energy to overcome the friction of the swing. When the weight reaches the end of its tether, it needs to be wound back on to the drum again using a special key.

How do fountain pens work?

Considered the king of all writing instruments, this pen has a complex design and structure

Fountain pens work, in general, by transporting ink from a sealed container (usually a cartridge) through a hole, into a finned feed and down to the tip of the nib. As the nib comes into contact with a surface, such as a sheet of paper, the ink is drawn out of the nib through capillary action, causing more ink to be drawn through the feed from the sealed container. Importantly, as the container is sealed, a vacuum is created within as the ink is removed and this – in partnership with the ink's surface tension as well as its molecular attraction to the pen's metal nib – causes it to flow in a controlled and consistent way. It also means the ink ceases to flow when the nib is lifted.

Fountain pen teardown
We break down a typical fountain pen to see how it writes with such finesse



Nib
The point of contact for the pen, the nib narrowly distributes ink onto a writing medium like paper. Nibs are commonly made from gold plate to avoid corrosion.

Cap
A protective cover for the delicate pen nib, the cap is often installed with a clip for easier portability.

Feed
Arguably the most important part of the pen, the feed controls the flow of ink out of the reservoir and distribution to the nib. The feed on a modern pen is commonly made from hard rubber or vulcanite.

Barrel
The casing for the internal components, the barrel tends to be made from plastic or lightweight metals. It is often tapered for ergonomic purposes.

Reservoir
A sealed container, such as a cartridge, that holds the pen's ink. Ink is drawn from the reservoir into the feed for controlled distribution.

Section
The lynchpin of the pen, the section holds together all of the various parts within the barrel and cap, including the feed, breather tube and nib.

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The first electric washing machine

Today they are a staple appliance few of us could live without, but where did they begin?

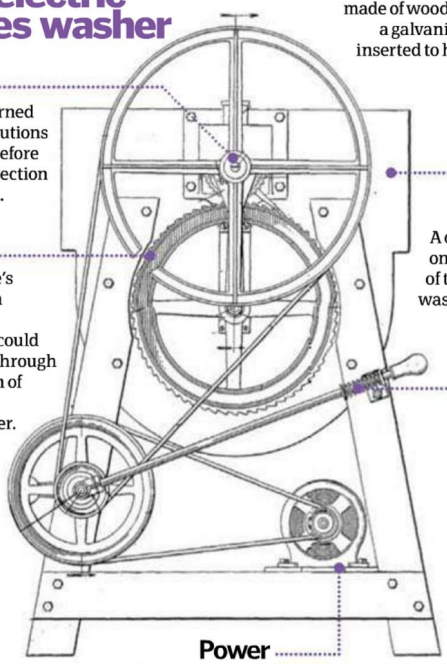


An early-20th-century washing machine similar in design to the first commercial washer the Thor

The first mass-marketed electric washing machine was the Thor, a tumble washer produced by the Hurley Machine Company in 1908.

The machine worked by tumbling clothes with a wooden drum, in two directions, at eight revolutions per minute. The drum's rotation mechanisms were powered by a single Westinghouse Electric Company electric motor and connected together via drive belts. Most innovatively, however, the Thor featured an integrated clutch, which allowed the machine to switch revolution direction and also be held in a stationary position once power was supplied. For a closer look at the machine's inner workings see the diagram to the left.

Inside the Thor electric clothes washer



Drum
The Thor's drum was made of wood, into which a galvanised tub was inserted to hold clothes.

Spin
The drum turned at eight revolutions per minute before reversing direction to spin again.

Clutch
A control lever on the left side of the machine was operated to engage and disengage its clutch.

Wringer
The machine's chain-driven wringing mechanism could be reversed through the operation of a top-right-mounted lever.

Power
Unlike modern machines, the Thor did not have an on/off switch, instead requiring users to physically disconnect its power cord to turn it off.

Amps explained

What are audio amplifiers and how do they work?

An audio amplifier is a device that responds to a small input signal – these can be in the form of voltage, current or power – and generates a larger output signal that retains the waveform features of the former. This process is used to increase the power of any given signal to increase the volume produced by a loudspeaker. The larger the signal, the larger the speaker driver operable. This is particularly desirable when refined, delicate sounds, such as those generated at a concert by instruments and human vocal chords, need to be stepped up to high-decibel levels, but without losing any depth or clarity.

The amplification action of most amplifiers is provided either by electromechanical devices – such as transformers and generators – along with vacuum tubes or solid-state microcircuits where thousands of micro transistors are installed on tiny silicon chips. Often, to ensure signal quality as well as strength, multiple amplification units are used in an array, with the original signal passing through both pre- and post-amplifiers before finally arriving at the loudspeaker.



Amplifiers are a rock band's best friend


A typical after-market car amplifier

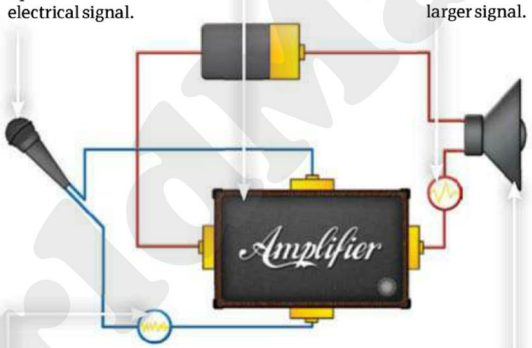
Amplifying basics

1. Mic
Sounds cause a mic's diaphragm to move back and forth. The mic converts this into a patterned electrical signal.

2. Small current
Due to the heightened sensitivity of the mic's diaphragm, the electrical current it produces is small and weak.

3. Modification
The amp produces a larger current, modified according to the original's pattern of charge fluctuation.

4. Large current
A larger patterned signal is produced to mirror the weaker one. The amp achieves this by applying varying resistance to the larger signal.



5. Overdrive
The stronger signal reaches the speaker's driver and is converted back into mechanical movement, generating a louder output.

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"When weight presses on the load cell, the strain gauge becomes deformed, altering its electrical resistance"

How do breadmakers work?

Discover how a handy kitchen appliance can speed up the bread-making process

A breadmaker is a semi-automated machine that greatly simplifies a laborious and time-consuming process. A typical breadmaker comprises a container with a hinged lid, an internal bread pan, heating element, kneading paddle and circuit board, plus an LCD control panel. The latter offers a range of pre-programmed cycles, each tailored to output a specific product, such as white and whole-wheat loaves or even pizza dough.

First the user removes the bread pan from the central cavity, before fixing the kneading paddle into the pan's base and depositing the ingredients on top. Now the bread pan returns into its chamber and the lid is closed. The user then selects the desired bread type, baking speed and crust via the LCD control panel and can either start the process immediately, or set it to begin at a specific time.

The ingredients are mixed inside the bread pan by the kneading paddle, while extra items such as yeast, water and flavourings are all added when needed. The dough is then left to rise, in a 'proofing' stage. Once proofed, a heating element activates. The element's temperature is controlled via a sensor on one of the cavity's walls. Baking proper then commences, with the dough generally cooked over 35-50 minutes, followed by a cooling period.

At this point, the machine lets the user know the bread is ready to be removed, usually through a series of bleeps. Due to the pan being covered in a non-stick coating – commonly this will be diamond-fluorine – the finished loaf can simply be dropped out ready for cutting and serving.

Anatomy of an auto-baker

We look at the main features that enable a breadmaker to cook up a perfect loaf



Heating element
At the bottom of the bread pan cavity is the breadmaker's heating element and temperature sensor. The element cooks the bread once activated by the control panel.

Control panel
Various cycles come pre-programmed on each breadmaker, allowing the user to create a variety of breads. These are selected via an LCD control panel.

Electric motor (internal)
Installed within the base of the unit, the motor powers the breadmaker's paddle, typically via a drive belt.

Bread pan
Resembling a metal bucket, the bread pan is both the mixing bowl and oven of the breadmaker. Typically, the pan has a non-stick coating, allowing the bread to be removed easily post-bake.

Paddle array
This sits in the bottom of the bread pan. The blade-like paddle rotates to knead the bread mixture prior to cooking.

Weighing up Wi-Fi digital scales

How do these web-connected scales help us stay on top of our weight and fitness?



Wi-Fi body scales are a specific variety of digital weighing instrument that links to the web via a wireless connection. Digital weighing scales work differently to traditional spring-based varieties by using a combination of a load cell and strain gauge. The burden placed on the scale presses down on the load cell (a form of transducer), which causes a strain gauge (a metal foil lattice bonded to a circuit board) to become deformed, altering its electrical resistance.

The strain gauge's resistance changes as, when an electrical conductor is stretched within the limits of its elasticity, it warps its material structure, decreasing the amount of electrical current that can pass through. The heightened resistance is detected by the scale's circuitry (typically via a Wheatstone bridge) and converted into a numerical reading displayed on the digital panel.

Wi-Fi scales take this basic functionality and introduce a wireless network access port, which allows them to connect to the internet via the user's home router. This web connection means that any reading taken on the scales can be uploaded and stored remotely. Remote access is generally granted through manufacturer-specific websites and smartphone/tablet apps that can be synced to a specific set of scales and then present the data either numerically or graphically.

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How do ovens cook food?

How different types of cooker provide us with a hot meal

There are two main varieties of household oven – gas and electric – with a few hybrids between the two.

The former work by burning gas to warm a heating element and/or a metal cooking compartment directly. The gas supply is ignited using an electric lighter that proceeds through one or more burner units to warm the air in the oven compartment(s) to the temperature designated by the thermostat.

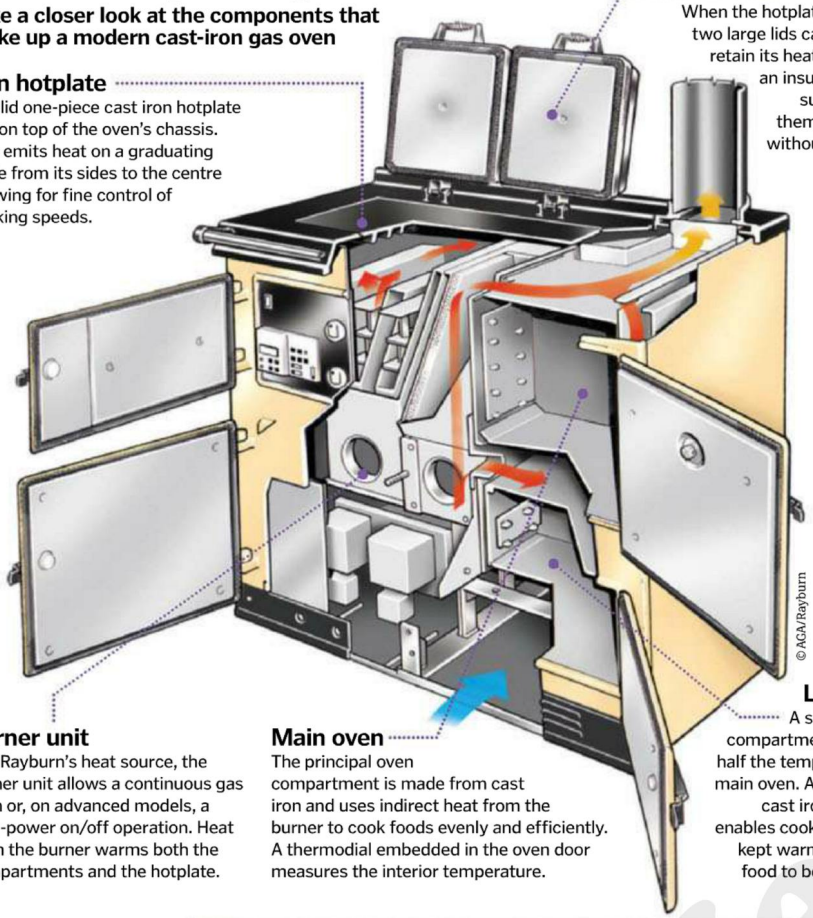
Within the category of gas ovens there are two major types: those that use heating elements – strips of metal in the top and bottom of the oven, and those that heat a metal cooking compartment directly. In both cases, the oven works by emitting thermal radiation, either baking (heated from below) or broiling (heated from above) the food. As a general rule, compartments utilise indirect heat, while elements point heat in a specific direction.

Electric ovens also come in two main flavours: standard thermal radiation and convection. Thermal electric ovens work on the same principle as their gas counterparts, with metal elements. Here the energy source is electricity, which passes as a current through the inner, coiled wires of the elements.

Convection ovens are of similar construction to standard thermal radiation cookers but introduce an air-circulating fan into the mix. This fan, which is installed in the rear wall of the oven cavity, aims to distribute the directed radiation from the heating elements around the oven, thereby delivering a more even spread of heat and a faster, more balanced cooking environment as a result.

Inside a Rayburn gas oven

Take a closer look at the components that make up a modern cast-iron gas oven



Insulated lids
When the hotplate is not in use, two large lids can be closed to retain its heat. The lids have an insulated, polished surface allowing them to be handled without oven gloves.

Iron hotplate
A solid one-piece cast iron hotplate sits on top of the oven's chassis. This emits heat on a graduating scale from its sides to the centre allowing for fine control of cooking speeds.

Burner unit
The Rayburn's heat source, the burner unit allows a continuous gas burn or, on advanced models, a high-power on/off operation. Heat from the burner warms both the compartments and the hotplate.

Main oven
The principal oven compartment is made from cast iron and uses indirect heat from the burner to cook foods evenly and efficiently. A thermodial embedded in the oven door measures the interior temperature.

Lower oven
A secondary oven compartment operates at half the temperature of the main oven. Also made from cast iron, this section enables cooked items to be kept warm or for certain food to be slow-cooked.

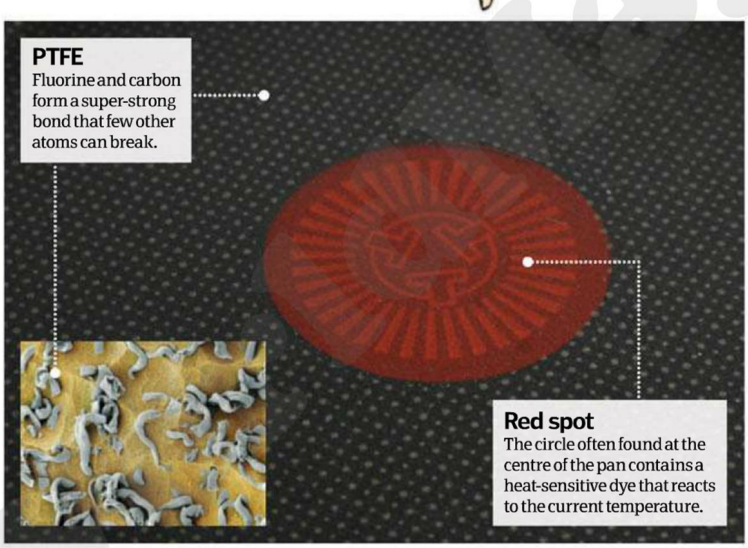
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Teflon explained

Find out why coating cookware in Teflon gives it an amazing non-stick finish

Teflon is made from polytetrafluoroethylene (PTFE) and it is used to coat cooking pans and other cookware giving them wonderful non-stick properties.

PTFE is composed of carbon and fluorine atoms which form very strong chemical bonds with each other. Fluorine also has the highest electronegativity of any element, meaning the overall electrical forces, known as van der Waals forces, cause compounds containing fluorine to repel any other atoms that come near. The fluorocarbon molecule is structured in a way that the fluorine surrounds the carbon so no other outside atoms can get anywhere near the carbon. As a result Teflon is highly unreactive causing it to have a very low coefficient of friction allowing things to slide across its surface very easily. Due to PTFE's reluctance to react with anything, it is also used to coat containers of highly reactive chemicals and, interestingly, is the only known material that a gecko can't stick to.



PTFE
Fluorine and carbon form a super-strong bond that few other atoms can break.

Red spot
The circle often found at the centre of the pan contains a heat-sensitive dye that reacts to the current temperature.

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"These refrigeration units worked under the same principles as modern fridges"

How did the first electric refrigerators work?

They're often taken for granted today, but refrigerators were once a groundbreaking and luxury appliance

Back in the Twenties, one electric refrigeration company dominated the market: Kelvinator. Its wooden cold box/compressor combo cost $714 (nearly $9,800/£6,100 today) – way beyond the pocket of the average household. So, with the goal of bringing more affordable refrigerators to the masses, General Electric ploughed $18 million into making the GE 'Monitor-top' fridge.

They were called Monitor-tops because the cabinet was all steel and the condenser was sealed in a cylindrical enclosure on top, which made it look like the turret from a 19th-century ironclad warship – the USS Monitor.

These refrigeration units worked under the same principles as modern fridges. By using a compressor, a circulating refrigerant was transformed from vapour into a liquid and cooled to near-room temperature under pressure, before being released back into circulation. The sudden change in pressure caused the refrigerant to turn into a vapour again, which had to draw heat from the air inside the cabinet, ultimately cooling it.

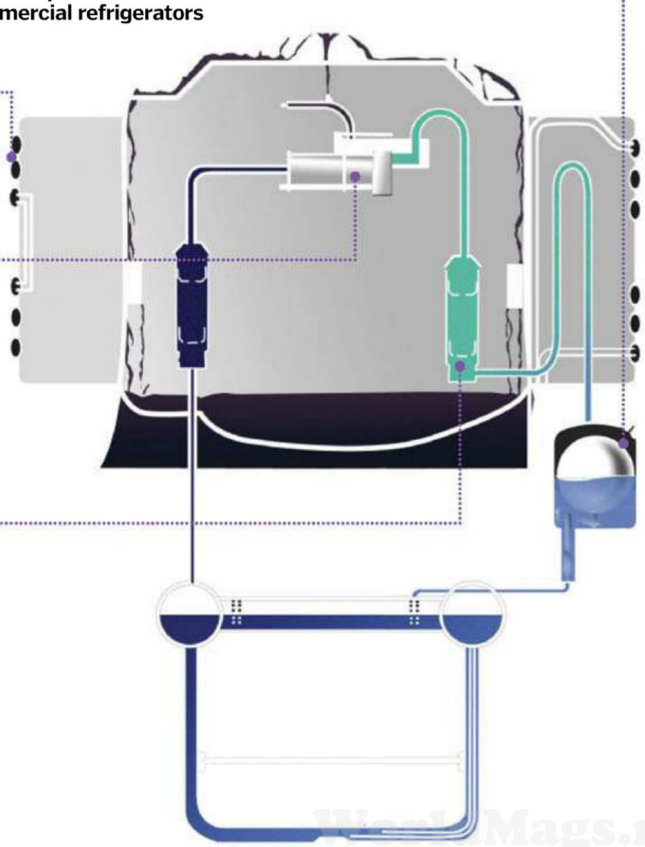
Several models of the Monitor-top refrigerator were made, including two and three-door units, but the most popular was the single-door variant, which originally sold for $300 in 1927.

Toxic origins

Today, the inert tetrafluoroethane gas R134a is commonly used in fridges and freezers, but in the Twenties refrigerants like sulphur dioxide, methyl formate and methyl chloride were used. These are quite toxic: sulphur dioxide causes burns on contact and can damage vision, methyl formate is highly flammable, while methyl chloride, or chloromethane, can cause dizziness, nausea and even seizures at high concentrations. These nastier chemical refrigerants were replaced by Freon, a relatively harmless gas that, nevertheless, was banned in the production of new fridges in 1990 over concerns about CFCs' effect on the ozone layer. Monitor-top fridges have become quite collectable now, the steel build ensuring many have survived for nearly a century. They are usually converted, with the dangerous gases removed and a modern compressor system installed to be eco-friendly.

Inside a Monitor-top fridge

We highlight the major components that made up one of the first commercial refrigerators



Heat-exchanging pipes
The liquid refrigerant, warm from compression, is passed around a series of pipes and cooled to room temperature.

Compressor pump
This pushes the refrigerant around the unit and compresses the refrigeration vapour.

Liquid refrigerant
The compressor applies pressure to the methyl formate gas in the Monitor-top fridge, which transforms it into a liquid.

Refrigerant vapour
The cool refrigerant liquid is passed through a valve and expands back to a partial gas state, taking heat from the air in the cabinet in the process.



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Rotary dial telephones

For many decades our household telephones sported a spinning dial, but how exactly did they work?

A rotary dial telephone was a popular type of telephone design throughout the 20th century. This communication device dials numbers in a very different way to the more modern push-button systems that we're familiar with today, requiring the user to rotate a numbered dial to key in digits and phone a number rather than press a series of buttons.

The rotary dial works on a pulse-based system. The frequency of pulses is determined by the number on the dial which the caller selects, with the user manually turning the dial to a fixed point with their finger before releasing it. This causes the dial to return to its starting position due to an internal recoil spring, while simultaneously generating a series of electrical pulses that interrupt the flow of current on the telephone's line.



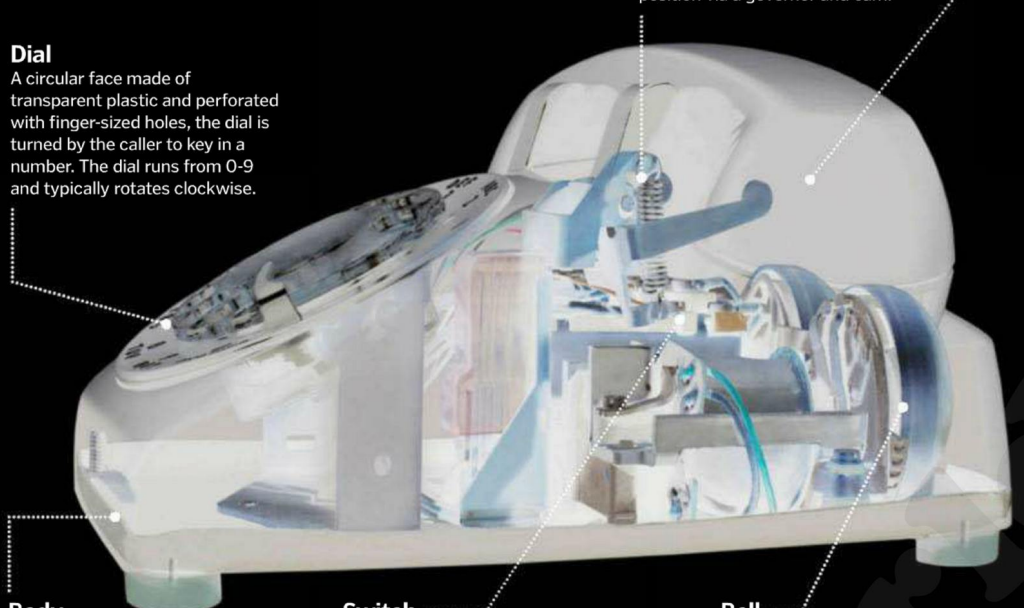
These pulses correspond to the digit selected, so if the user rotates the dial from, say, '7', then seven pulses will be sent down the line to the switching office.

Inside the body of the rotary telephone a centrifugal governor ensures that the dial's rotation is moderated to a constant rate, with a shaft on the governor turning a cam that opens and closes a switch contact. If the contact is open, the line's current is then stopped from flowing, thereby creating a dial pulse, while when closed, there is a constant flow of current.

At the electromechanical switching office, these pulses are received by a sender system, which records the pulses – ie the number that has been dialled – before routing it to a selector system which makes the outgoing connection to the telephone of the appropriate property.

Making the call

Take a look at the main components that make up these traditional communication devices



Dial
A circular face made of transparent plastic and perforated with finger-sized holes, the dial is turned by the caller to key in a number. The dial runs from 0-9 and typically rotates clockwise.

Recoil spring
As the dial needs to be rotated a number of times, it connects to a spring. This returns the dial to its starting point and moderates its movement speed and the switch position via a governor and cam.

Receiver
As with a modern phone, the user speaks through a handheld receiver, with the handset comprising both receiver and transmitter ends. When resting on the phone's cradle, the line is in a receptive state.

Body
The body is faced with the dial mechanism and contains the core components of the system. It is generally made of moulded plastic like Bakelite, though early units were built from wood and metal.

Switch
This electrical contact dictates the phone's pulse generation. When a user keys in a number, the movement of the dial forces the contact to open and close to create a specific number's dialling pulse.

Bell
When an incoming call is awaiting connection, a brace of mechanical bells at the rear of the body are struck by a hammer to produce a ringing noise. Once the handset is lifted, the hammer is disengaged.

The rise of touch-tone

In 1950 US network operator AT&T ran a series of trials which proved that push-button dialling was roughly twice as efficient as rotary dialling. This led to the company releasing an electronic push-button system known as 'Touch-Tone' to its customers in 1963, which quickly gained popularity thanks to its speed – both at the user end and at the network end. The touch-tone system, which is still in use throughout the world today, works through dual-tone multi-frequency (DTMF) signalling where each of the dialling digit buttons is assigned a specific frequency; columns have higher-frequency tones while rows have lower ones. As such, when a button is pressed, a dual-tone signal is generated that corresponds directly to the frequency assigned to a specific telephone number.

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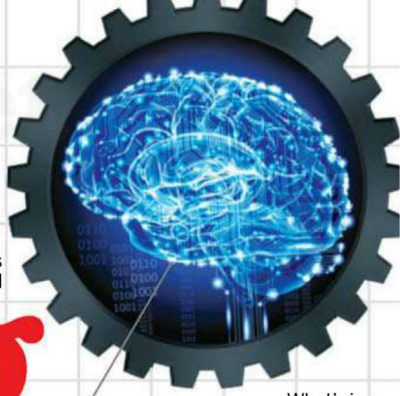


The science behind tumble dryers

HOW IT WORKS BOOK OF Amazing TECHNOLOGY



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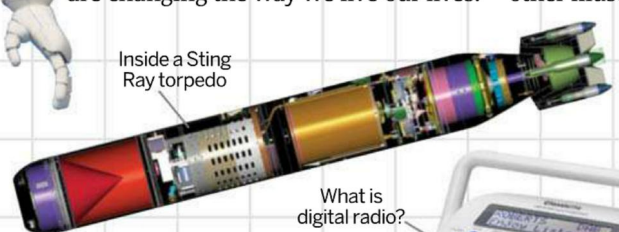
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